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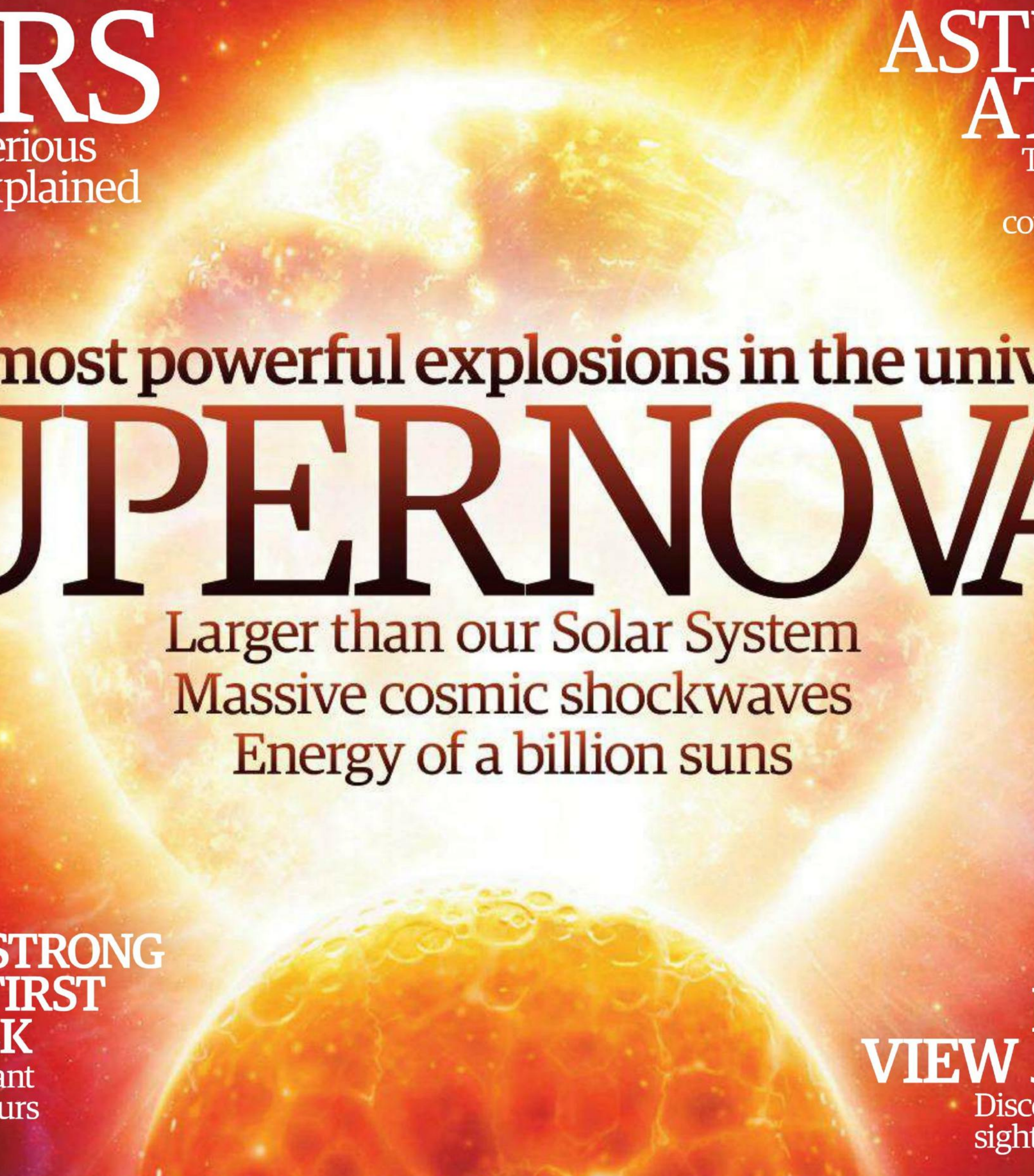

The most powerful explosions in the universe

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Larger than our Solar System
Massive cosmic shockwaves
Energy of a billion suns

NEIL ARMSTRONG AND THE FIRST MOONWALK
The most significant two-and-a-half hours in space history

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NASA'S COMET HARPOON
THE SEARCH FOR SPACE ICE
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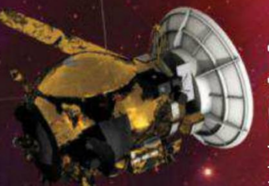

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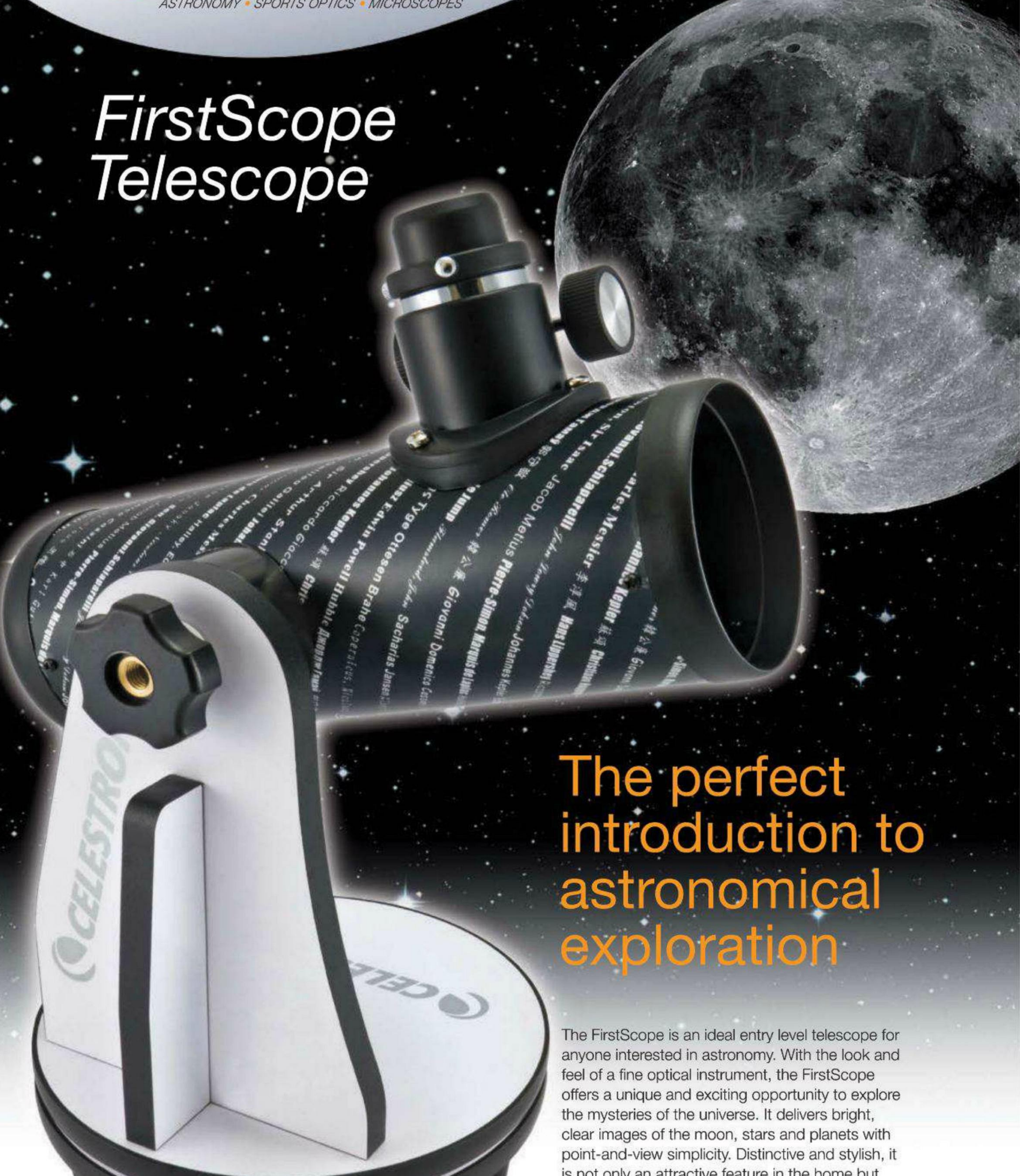

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Blast off into a universe of knowledge

Welcome to the fifth issue of **All About Space**. Given the infinite and fascinating nature of the cosmos it should come as no surprise that we're never short of amazing subjects to cover in our pages. Take, for example, supernovas; these massive stellar explosions are the largest in the universe and can equal the energy of a billion Suns! While they last for just a week or so they can shine as bright as a galaxy of 100 billion ordinary stars. The elements created and released by supernovas play such an important role in the formation of new stars and planets that many of the elements that make up our very own bodies were forged in these colossal explosions that are the subject of our main feature this month, beginning on page 16.

On 13 September 2012 a huge chunk of space rock the size of the Eiffel Tower whizzed past Earth at 40,200km/h (25,000mph), missing us by just 2.7 million kilometres (1.7 million miles) - about seven times the distance between Earth and the Moon. It was spotted only a couple of weeks prior to this and was classed as 'potentially hazardous', meaning its orbit may well cross Earth's in the future. Some asteroids actually come so close as to pass between Earth and the Moon, a hair's breadth in cosmic terms. We wanted to learn more about the people who track these giant rocks which could potentially destroy our world; find out more on page 28. Enjoy the issue!

Dave Harfield
Editor in Chief

> "Some asteroids actually come so close as to pass between Earth and the Moon"

Crew roster

Jonathan O'Callaghan

■ Although the fiery and volatile subject of supernovas is in direct contrast to his placid nature, Jonny still managed to write an excellent feature on them

Shanna Freeman

■ With so much attention currently on the Curiosity rover, there was no better time for Shanna to use her space knowledge to pen an in-depth feature on Mars

Tom Kerss

■ Professional astronomer Tom joins us once again to contribute to our Stargazing section, showing us what to see on the gas giant Jupiter and elsewhere in the galaxy

Tom Harris

■ He's as solid as a rock and can move at blistering speeds – both traits which served Tom well while writing a truly eye-opening article on asteroids

Dave Roos

■ Continuing his secondment from **How It Works** magazine, Dave reveals all about events during the legendary first moonwalk on page 54

Dr Ken Kremer

■ Dr Kremer's naturally enquiring mind served him well when researching and answering readers' questions in our Space Answers section

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YOUR FIRST CONTACT WITH THE UNIVERSE

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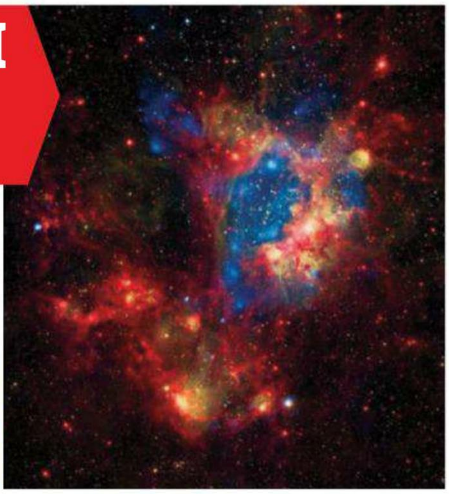

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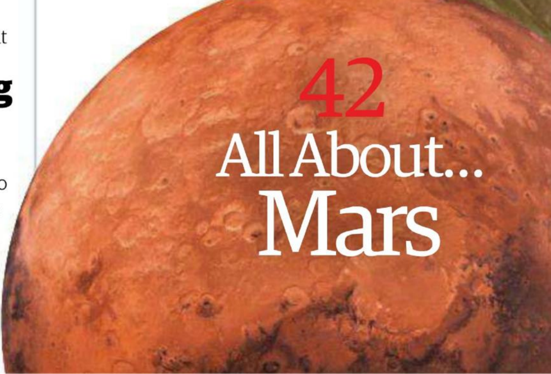

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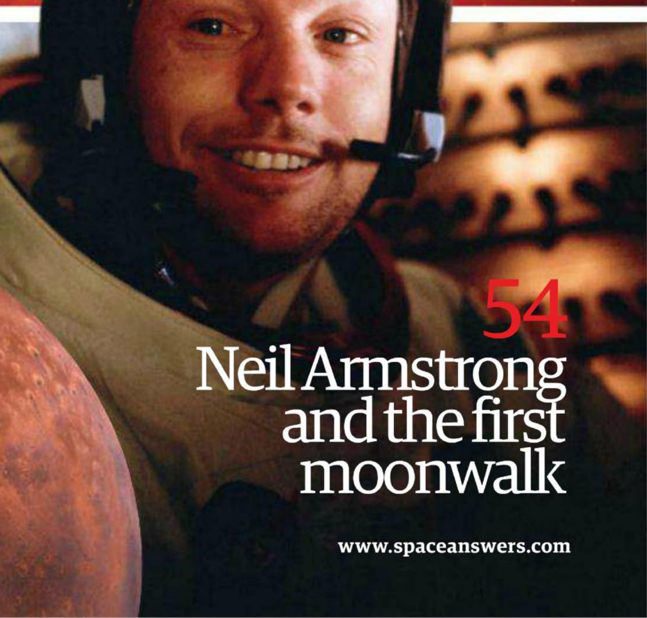

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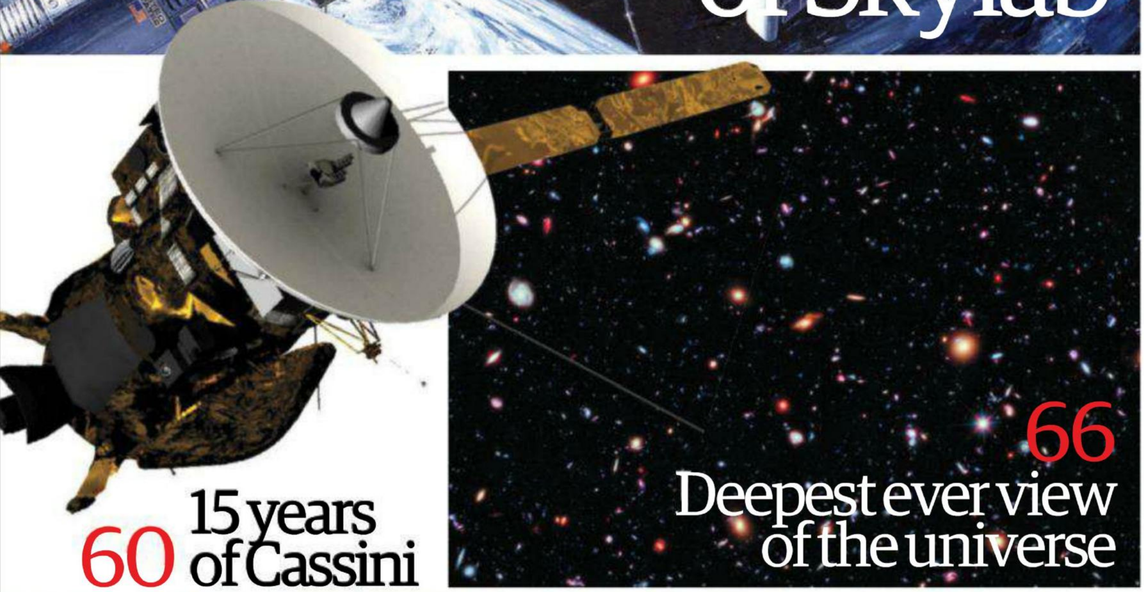

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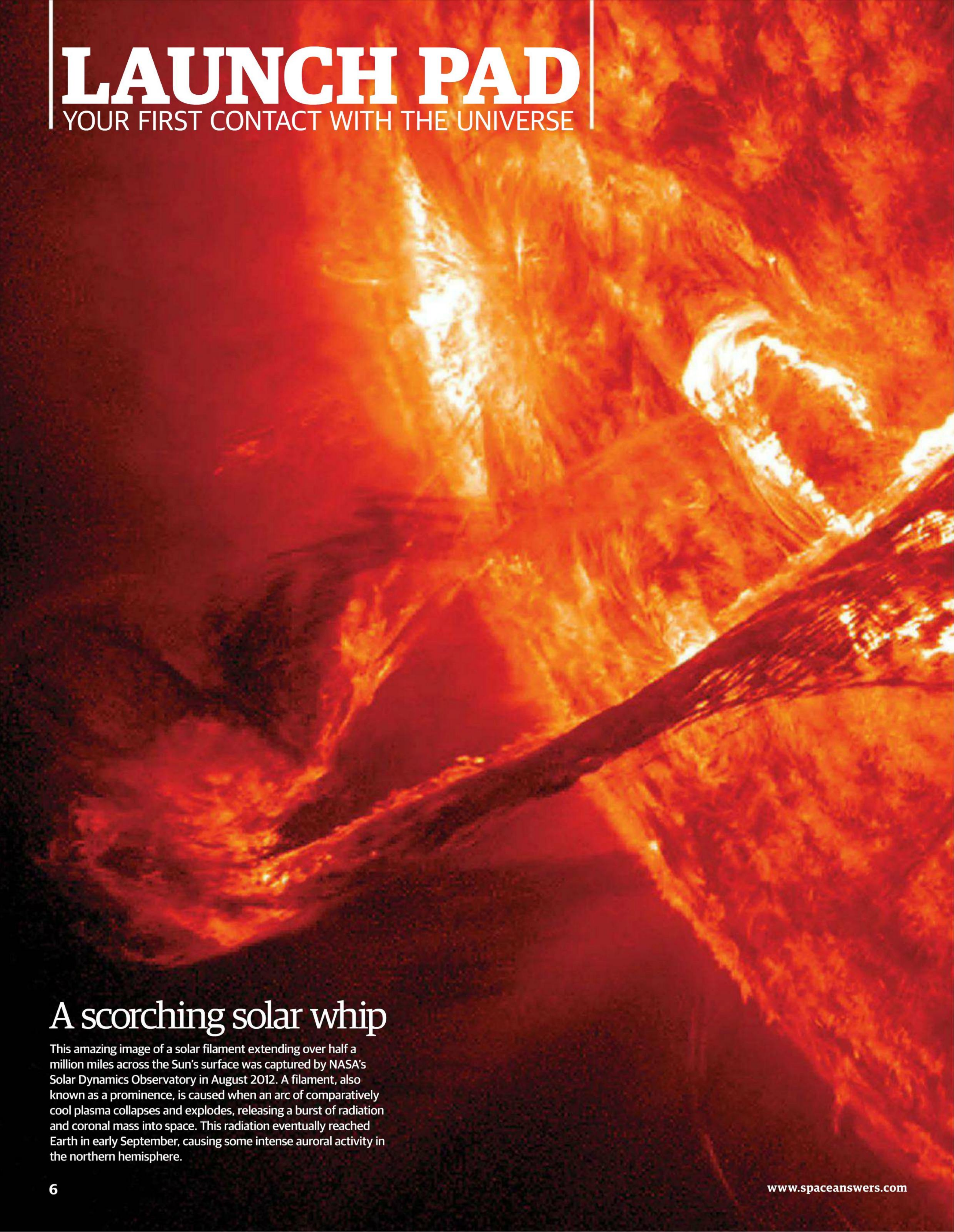
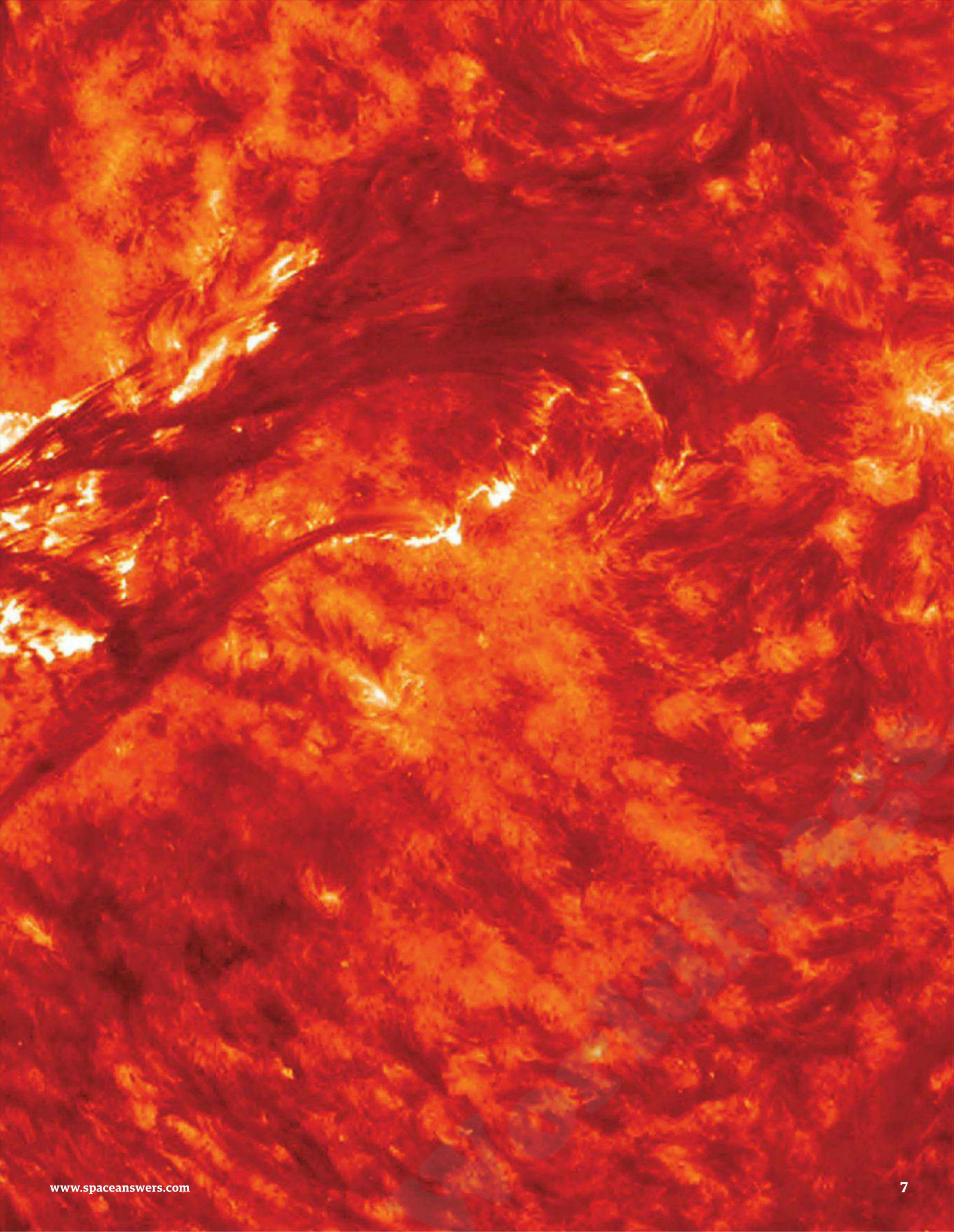
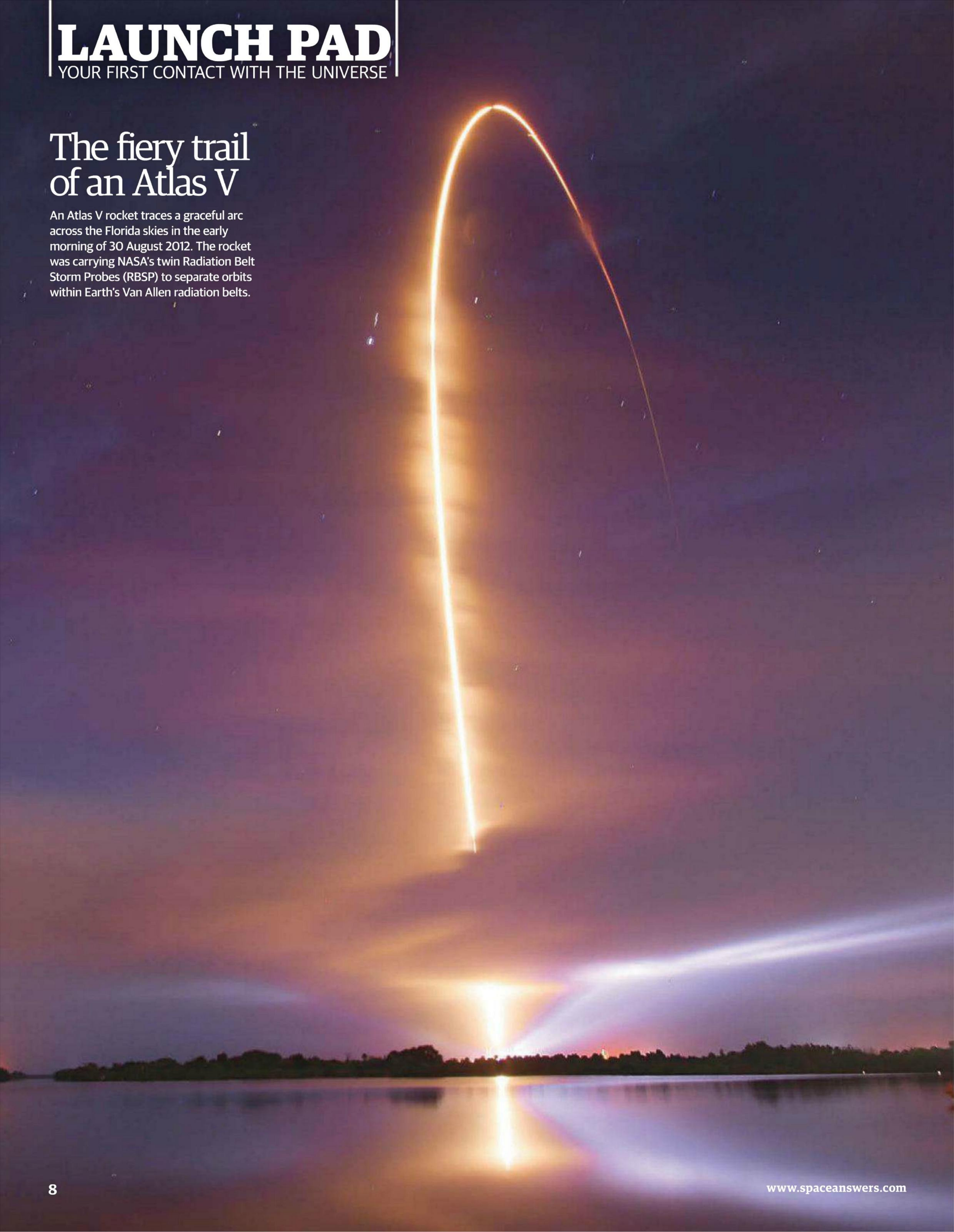


A scorching solar whip

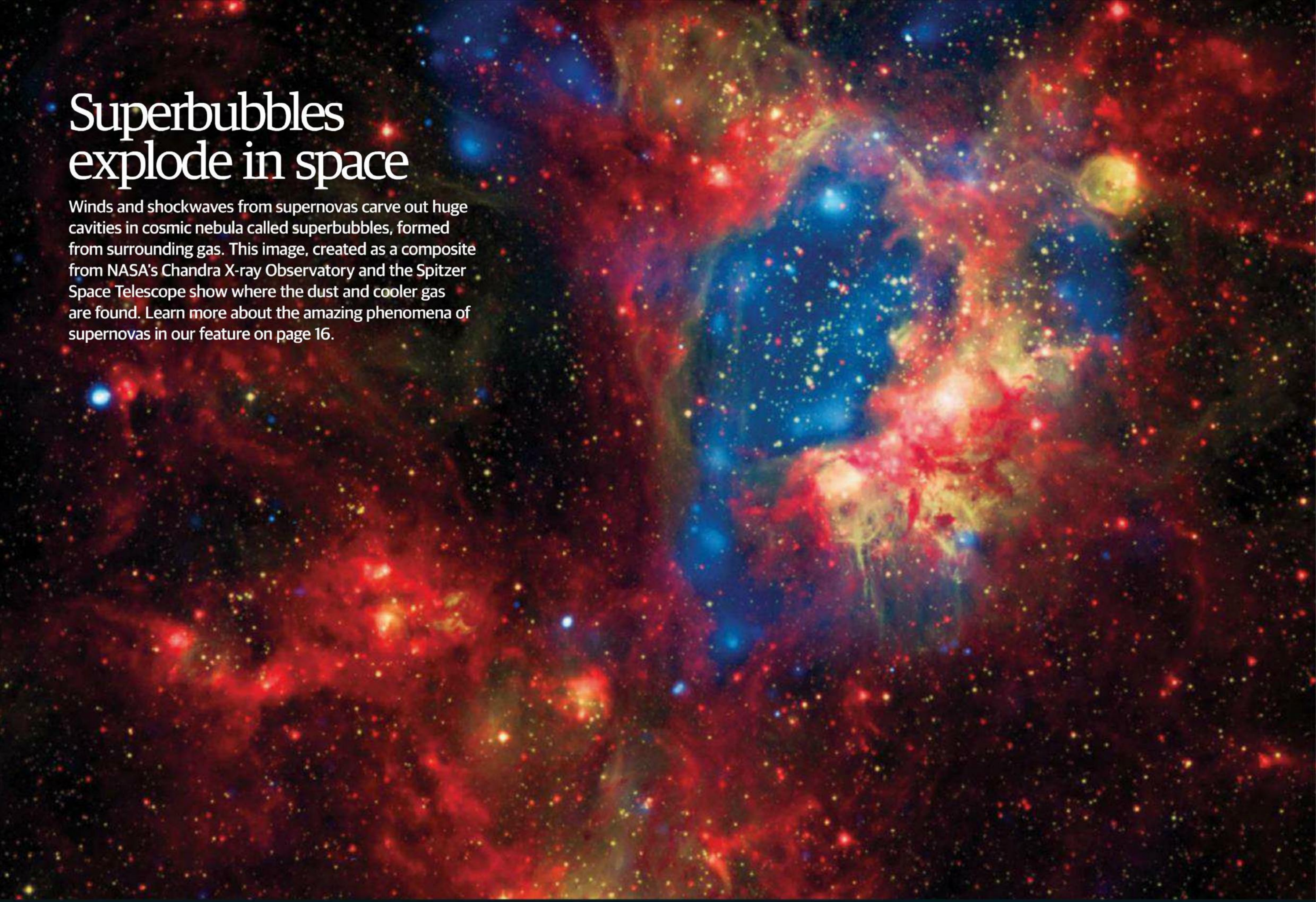
This amazing image of a solar filament extending over half a million miles across the Sun's surface was captured by NASA's Solar Dynamics Observatory in August 2012. A filament, also known as a prominence, is caused when an arc of comparatively cool plasma collapses and explodes, releasing a burst of radiation and coronal mass into space. This radiation eventually reached Earth in early September, causing some intense auroral activity in the northern hemisphere.





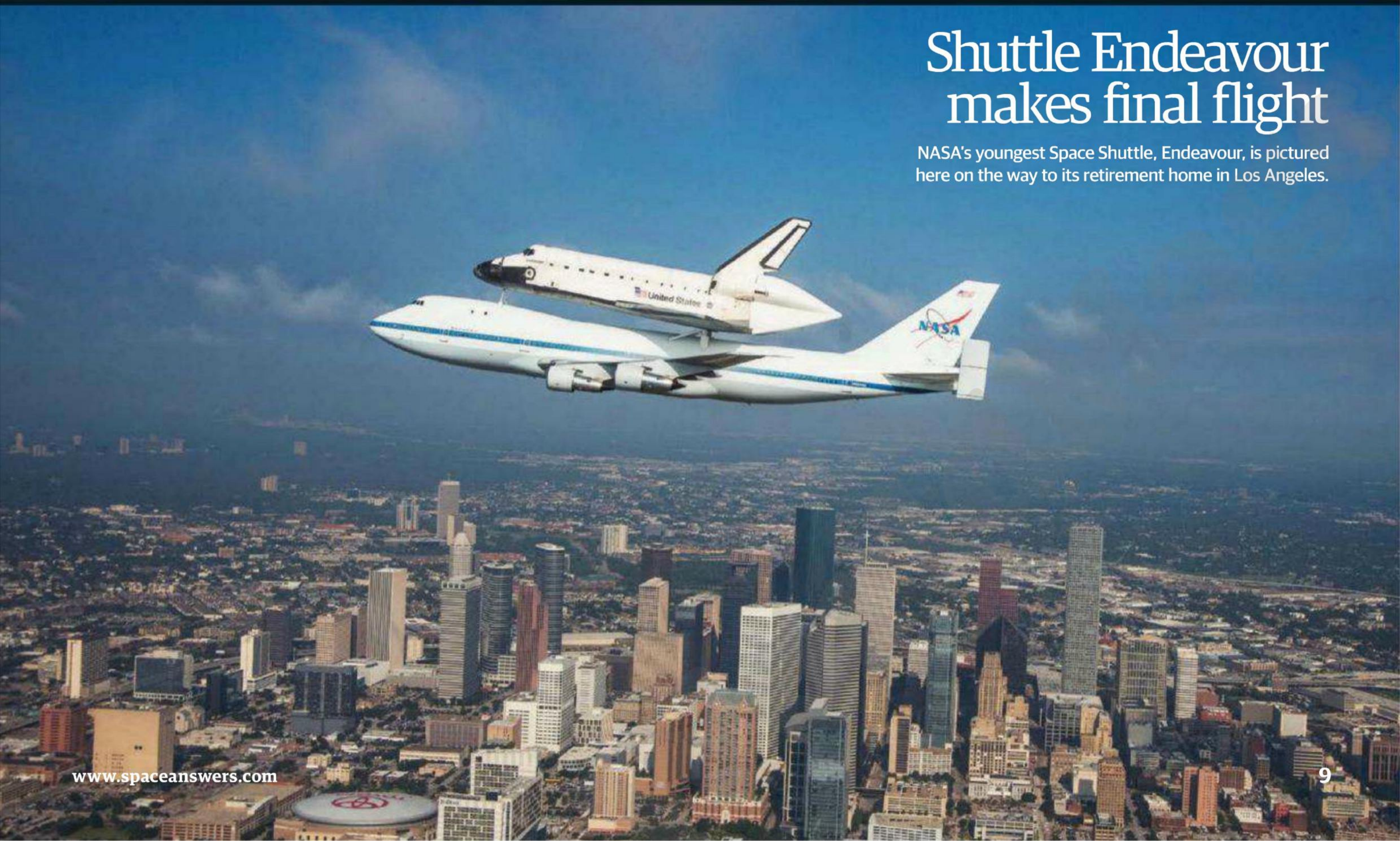
The fiery trail of an Atlas V

An Atlas V rocket traces a graceful arc across the Florida skies in the early morning of 30 August 2012. The rocket was carrying NASA's twin Radiation Belt Storm Probes (RBSP) to separate orbits within Earth's Van Allen radiation belts.



Superbubbles explode in space

Winds and shockwaves from supernovas carve out huge cavities in cosmic nebula called superbubbles, formed from surrounding gas. This image, created as a composite from NASA's Chandra X-ray Observatory and the Spitzer Space Telescope show where the dust and cooler gas are found. Learn more about the amazing phenomena of supernovas in our feature on page 16.



Shuttle Endeavour makes final flight

NASA's youngest Space Shuttle, Endeavour, is pictured here on the way to its retirement home in Los Angeles.

01

Curiosity's adventures continue

Over two months have passed since the rover's successful landing and Curiosity continues to amaze with photographs of discoveries on the Red Planet's surface

1. A 360-degree view of the landing site of NASA's Curiosity rover.

2. The Chemistry and Camera (ChemCam) instrument on Curiosity used its laser to examine side-by-side points in a target patch of soil, leaving the marks apparent in this before-and-after comparison.

3. Tracks from the first drives of Curiosity are visible in this image captured by the High-Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter. The rover is seen where the tracks end.

4. A closeup of track marks from Curiosity's first test drive.

5. This image of exposed bedrock is the first ever evidence of an ancient flowing stream on the Red Planet. Taken on the 39th Martian day, or sol, by Curiosity's Mastcam, the rounded rocks are a clear indication of past water flow.

6. The penny in this image is part of a camera calibration target.

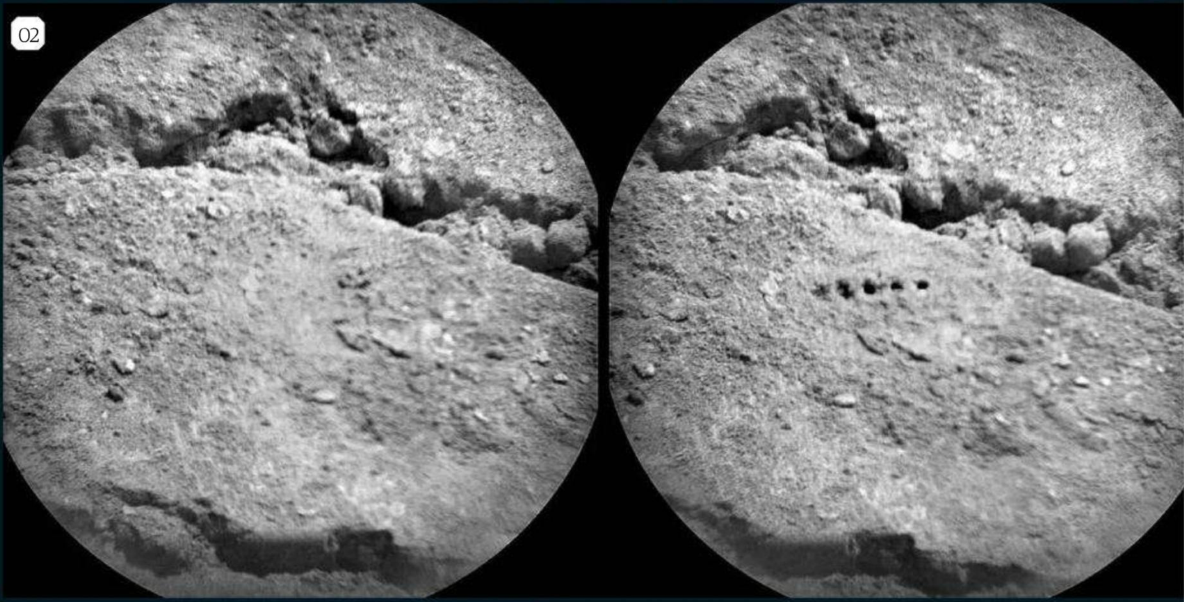
7. Analysing a rock called Bathurst Inlet with tools on Curiosity's arm.

8. Curiosity completes one of its longest journeys. The wheel tracks from the journey are visible in this black-and-white image.

9. This shot shows two of Curiosity's left wheels. The lower slope of Mount Sharp is in the distance.

10. The Alpha Particle X-Ray Spectrometer (APXS) with the distinctive red Martian landscape visible in the background.

02



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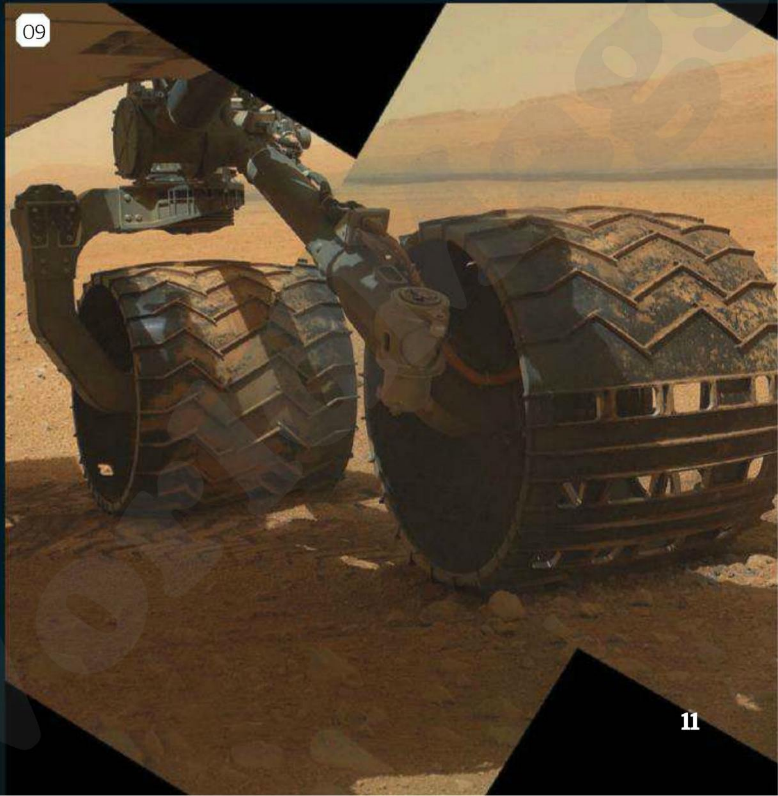
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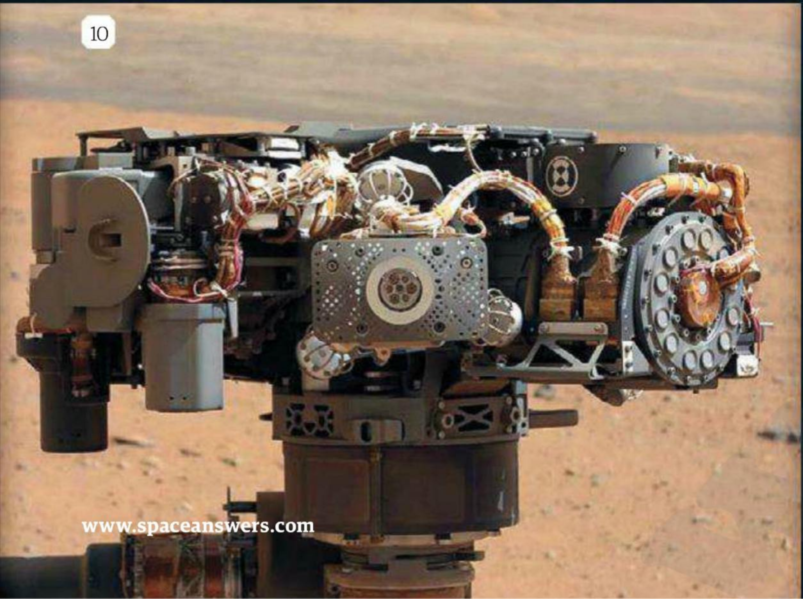
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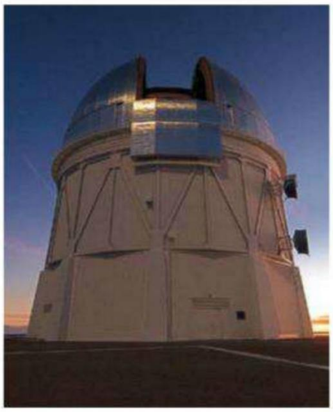
Super camera to reveal secrets of dark energy

Could one of the mysteries of the universe finally be solved?

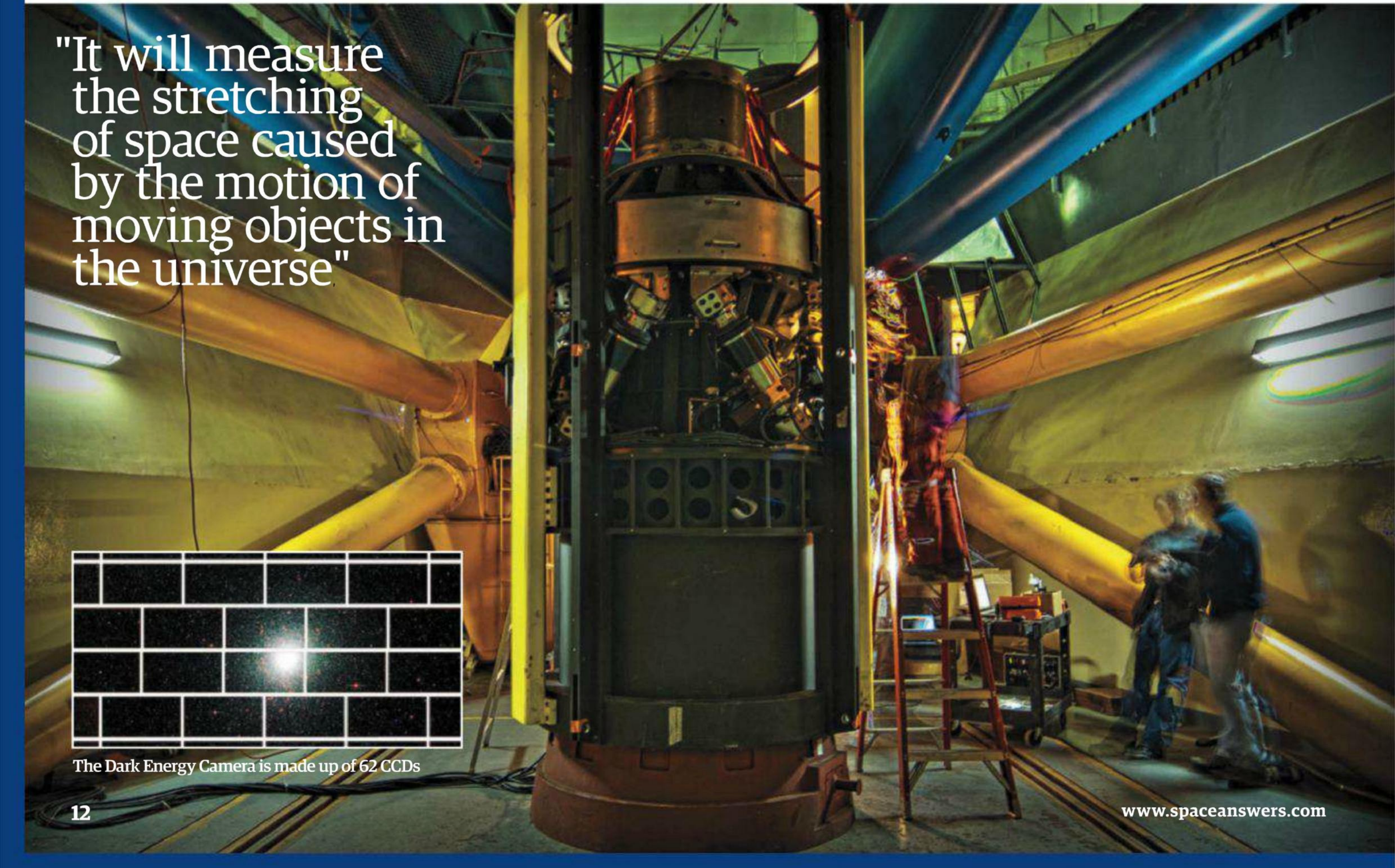
The 570-million-pixel Dark Energy Camera (DECam) in central Chile is gearing up to begin its five-year mission to scan 300 million galaxies in December. The project, called the Dark Energy Survey (DES), will use DECam – the most powerful sky-scanning camera ever built – to observe 100,000 galaxy clusters and 4,000 supernovas on its way to its ultimate goal, which is to discover what dark energy actually is.

The camera itself, located on the Blanco four-metre (13-foot) telescope at the Cerro Tololo Inter-American Observatory in Chile, will use a system of five lenses (the biggest of which is one metre/3.2 feet in diameter) to garner a wide-field view of the night sky. A collaboration between the US, UK, Brazil, Spain and Germany, the galaxy survey performed by this incredibly sensitive phone box-sized camera will be the largest of its kind. The camera will predominantly observe the universe in red and infrared light, allowing it to see up to eight billion light-years away. By doing so, it will measure the stretching of space caused by the motion of moving objects in the universe, known as 'redshift'. 120 scientists from 23 institutions are taking part in the project, which will be studying the southern sky in an attempt to understand if the majority of the universe as we know it, is indeed, 'missing' from view.

Dark energy is thought to be responsible for the accelerating expansion of the universe but, as of yet, no conclusive evidence for its existence has been found. According to Einstein's theory of general relativity, gravity should be slowing the expansion of the universe, but it appears that the expansion is actually speeding up. The culprit is thought to be dark energy, which may make up as much as 75 per cent of the universe, but its existence (and thus Einstein's theory) has not yet been confirmed. It is hoped that the ground-breaking DECam will change that and, by the end of the survey in 2017, we should have a much clearer picture of what is going on in the universe. ●



The 570-million-pixel DECam is based at the Cerro Tololo Inter-American Observatory in central Chile



"It will measure the stretching of space caused by the motion of moving objects in the universe"

The Dark Energy Camera is made up of 62 CCDs

ISS successor to be built beyond the Moon

NASA plans to build station 1,000 times farther into space

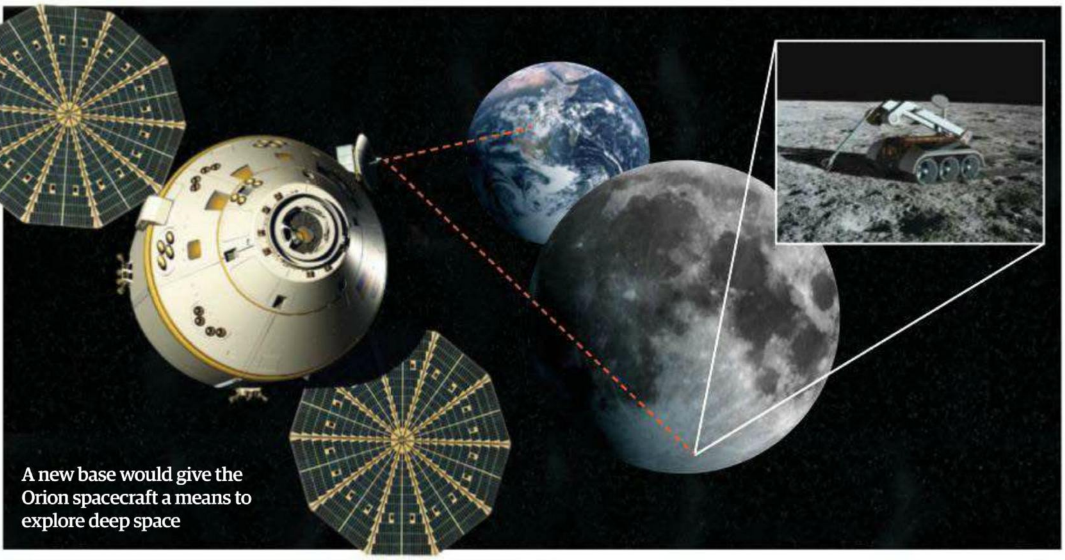
Leaked documents from NASA chief Charlie Bolden to the White House in September 2012 indicate that NASA is looking to build an orbital outpost 445,000 kilometres (277,000 miles) from Earth, over a thousand times farther than the International Space Station. It will provide an outpost from which spacecraft can be sent to the Moon, Mars and possibly beyond.

Hovering in orbit on the far side of the Moon, the so-called 'gateway spacecraft' would be able to support a small crew. Its primary purpose would be to enable deep-space human exploration missions farther than has ever been possible before.

The exact location of the space station would be 61,000 kilometres (38,000 miles) beyond the Moon, known as the Earth-Moon Lagrange Point 2, where gravitational equilibrium allows an object to remain stationary with respect to the Moon.

To construct the station, NASA would use parts from the ISS, due to retire sometime after 2020, and also launch new components with its planned Space Launch System heavy-lift rocket. NASA wouldn't undertake construction alone, though; reports suggest it would enlist the help of Russia, Italy and possibly others.

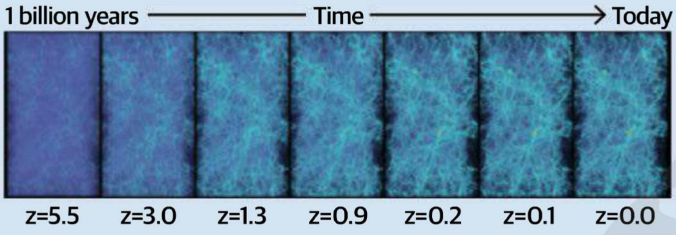
Such an endeavour, while being extremely costly, would enable extensive human exploration of the Solar System, especially if the Moon could be mined for useful materials such as fuel and water. It would also provide a solid destination for NASA's much-hyped Orion spacecraft, which is currently under development and has tentative plans to visit an asteroid in 2025, and Mars sometime during the following decade. ●



A new base would give the Orion spacecraft a means to explore deep space

Scientists to re-create the Big Bang

Project will shed light on the laws of physics



By November a project at the Argonne National Laboratory in Illinois will begin the most detailed simulation ever attempted: re-creating the universe from the Big Bang to today.

Running on the Mira supercomputer, the project will calculate the response of trillions of particles in simulated space and time. Taking up to two weeks to complete, the simulation will carefully track the interaction of the different particles as they clump together to create galaxies, just as they would have done during the formation of the real universe.

The project's goal is to compare our observations of the structure of the cosmos with the simulated structure to glean a better understanding of the laws of physics as a whole. ●

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Super-Earths may not be alien friendly

A new study suggests that terrestrial exoplanets larger than Earth may be less hospitable than previously thought. Researchers say that these giant planets might be unable to form either a molten core or a magnetic field.

Asteroid minerals found

NASA's Dawn spacecraft has found evidence of evaporated materials around the equator of giant asteroid Vesta. Likely originating in water, the pothole-like features indicate areas where evaporation has occurred.

Sea level changes traced by satellites

Using almost two decades worth of satellite observations, new maps of the change in sea level around the world have been made. Using data from a variety of spacecraft, the new research shows that parts of the world have seen significant increases, such as the Philippine Sea.

Europa's deep ocean

A subsurface ocean on Jupiter's moon Europa, if it exists, would be much lower beneath the surface than previously thought. Water can survive close to the surface for just tens of thousands of years, so the majority would be up to 50 kilometres (31 miles) underground.

Russia plans to re-focus on the Moon

National space agency may give up on more deep-space adventures

Russian Deputy Prime Minister Dmitry Rogozin, speaking to the Vesti FM radio station in Moscow, has said that his country should re-focus its troubled space programme efforts on building a lunar base.

"Why not try to build a big station on the Moon that would be a base for future 'leaps' of science," said Rogozin. "There is a lot of competition among countries in the space sector and so we must have a big super goal that could pull forward science and industry. That would enable the country to escape from the morass of problems, which have kept us captive for the past 20 years."

Russia currently has plans to send two unmanned missions to the Moon by 2020, and some reports suggest they are also considering a manned lunar mission. After seeing a mission to the Martian moon Phobos fail in late-2011, Russia's space agency might be keen to focus on a target a little bit closer to home and perhaps work towards a permanent lunar colony.

Biggest-ever mirrors prepped for space telescope

The James Webb Space Telescope's first two mirrors have been delivered

The first two of the giant James Webb Space Telescope's (JWST) 18 mirrors have been delivered to NASA's Goddard Space Flight Center in Greenbelt, Maryland, for inspection. Ball Aerospace & Technologies Corp in Boulder, Colorado, is responsible for building the mirrors, placing them in special containers after construction for delivery to NASA.

"These first two completed flight mirror assemblies arriving at Goddard are an important first step leading towards the integration of the mirrors onto the flight structure," said Lee Feinberg, NASA Optical Telescope Element Manager for JWST. "These delivered flight mirrors meet their requirements, which is great news for the Webb telescope being able to fulfil its scientific potential." Each of JWST's 18 mirrors measures 1.3 metres (4.2 feet) across and weighs 40 kilograms (88 pounds), combining to produce a mammoth primary mirror measuring 6.5 metres (21.3 feet) across. Over the next 12 months the remaining 16 mirrors will be sent from Ball Aerospace to Goddard with a view to telescope integration in 2015, ahead of the planned launch of JWST in 2018. The ESA and Canadian Space Agency are partners with NASA in the project.

JWST's primary goals upon launching will be to study the formation of stars and planets, and the birth and evolution of galaxies.

Named after James E. Webb, the second ever administrator of NASA, the telescope will also provide us with much better views of extra-solar planets, while hopefully attempting to discover habitable worlds outside our own Solar System.

> "Important first step leading towards the integration of the mirrors onto the flight structure"

The mirrors must be kept in a clean room to prevent any contamination of their highly reflective surfaces

What's happening in space...

OCTOBER

23

New ISS crew

Three new crew members taken to the ISS by a Russian Soyuz spacecraft.

29 FULL MOON

30

Endeavour retired

Space Shuttle Endeavour reaches its retirement home, the California Science Center in Los Angeles.

NOVEMBER

3

Laika the explorer

It will be 55 years since Soviet space dog Laika became the first animal to orbit the Earth.

7 QUARTER MOON

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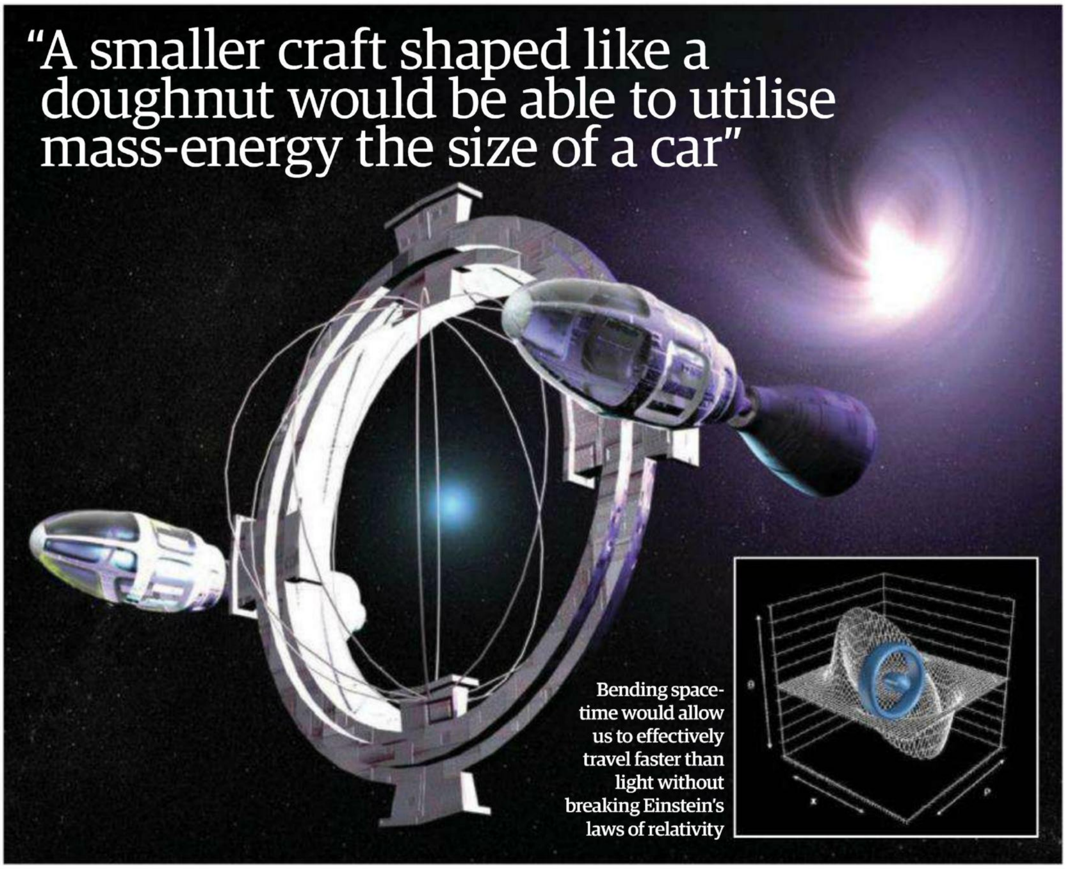
“A smaller craft shaped like a doughnut would be able to utilise mass-energy the size of a car”



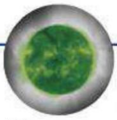
Bending space-time would allow us to effectively travel faster than light without breaking Einstein's laws of relativity

Warp travel breakthrough makes faster-than-light journeys a possibility

New research suggests bending space-time to travel beyond light speed is realistic

Scientists at the 100 Year Starship symposium in Houston, a meeting of scientific minds to discuss an interstellar voyage within a century, say that a warp drive as envisioned in Star Trek and other works of science fiction may not be as unrealistic as once thought. Theoretical warp drives that bend space and time would enable faster than light travel and, while the technology is centuries away, the dream may be possible.

In 1994 Mexican physicist Miguel Alcubierre proposed a concept for such a drive – a football-sized spacecraft within a ring that could move through space-time, but its major drawback was that it would require the mass-energy of a planet to power it. However, new research showcased by NASA scientist Harold White suggests that a smaller craft shaped like a doughnut (rather than the flatter design Alcubierre put forward) would be able to utilise mass-energy the size of a car instead to bend space-time and travel to distant locations in an instant.



13 NEW MOON

Total solar eclipse

Observers in Northern Australia and the southern Pacific Ocean are treated to a total solar eclipse.

17

Meteor shower

The Leonids peaks, with over 40 meteors per hour visible near the constellation of Leo.

20 QUARTER MOON

Q4

Private spaceflight

The Orbital Sciences Antares rocket performs a demonstration flight with the Cygnus spacecraft.

28 FULL MOON

*All dates are subject to change

Apps OF THE MONTH

Essential space-related apps

Pocket Universe: Virtual Sky Astronomy

For: iOS

Price: £1.49/$1.99

This fantastic app for iPhone and iPad lets you hold your device up to the night sky and identify every celestial object, from stars to planets. You can also take virtual tours of the Moon and Mars.

Solar Walk – 3D Solar System model

For: iOS

Price: £0.69/$0.99

If you want to learn about the planets and their moons then definitely pick this app up. The interactive environment lets you explore each world and find out information, all while zooming through space.

SkEye Planetarium

For: Android

Price: Free

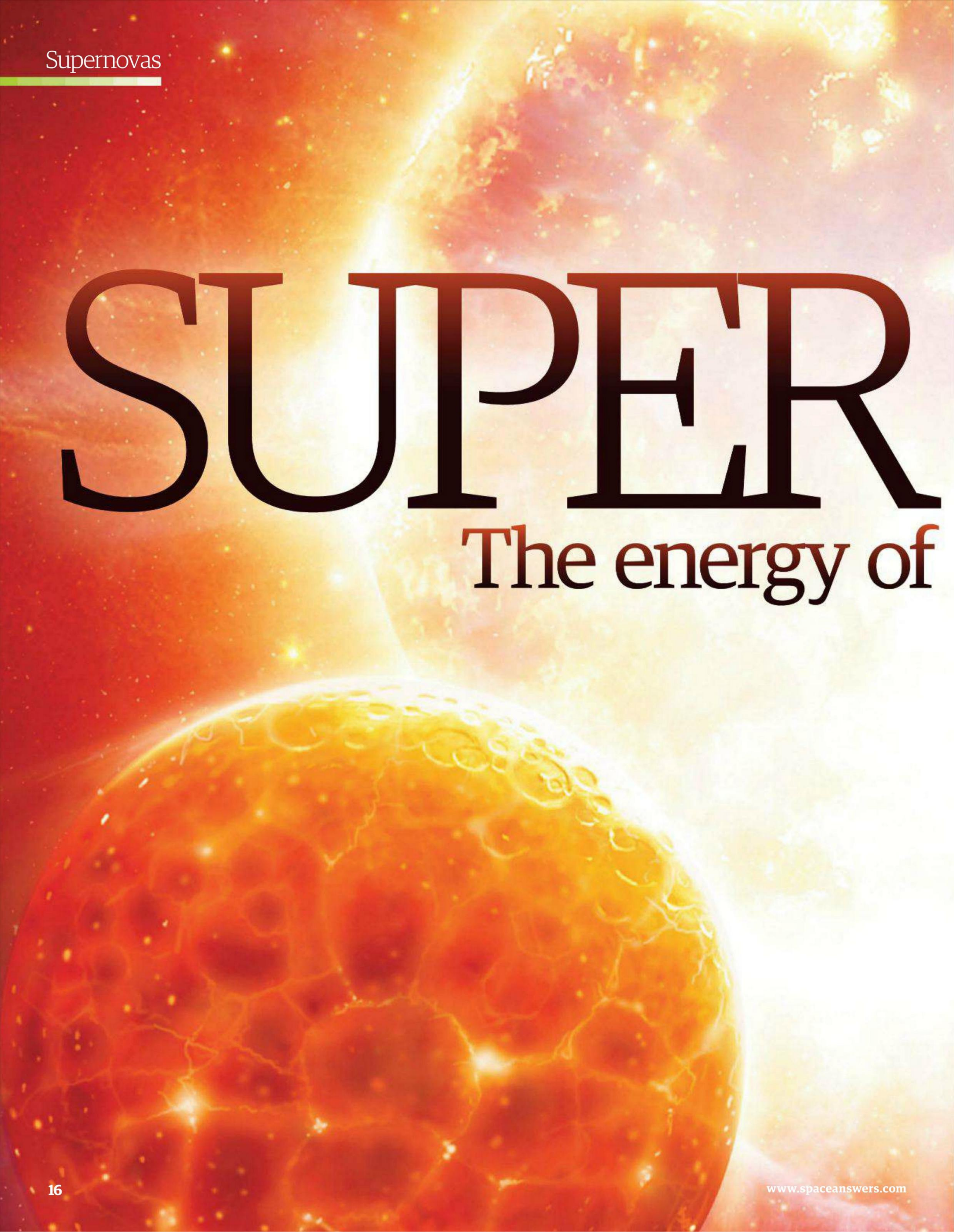
This advanced planetarium app can also be used as a PUSHTO device for telescopes, making it the perfect companion for amateur astronomers. You can also learn about the night sky and jump to any date in the past or future.

The Invisible Universe

For: Android

Price: Free

This app lets you see the night sky in its hidden colours, observing interstellar space like never before. You can view the universe in X-ray, ultraviolet and infrared wavelengths, and there is also detailed information on different space phenomena.



SUPER

The energy of

NOVAS
a billion suns

Written by Jonathan O'Callaghan

The massive stellar explosions capable of sending cosmic shockwaves across entire galaxies

Stars are large and volatile masses of energy, finely balanced to allow their existence to continue while also emitting large amounts of energy into their surroundings. Their very presence is one of the wonders of the universe, with these giant hot and dense balls of gas able to survive the harsh reality of space. But when the finely-tuned balance of gravity and pressure within a star is altered, something rather remarkable often happens. Try to imagine an explosion more powerful than a billion suns, and you might start to understand how stars can meet their explosive end when they go supernova.

In 185 AD, Chinese astronomers were astounded when a new star appeared in the night sky for eight months. The star appeared from nowhere and was stationary, ruling out the possibility of it being a comet. Although unknown at the time, those Chinese astronomers (and possibly Roman astronomers around the same period as well) unwittingly became the first people to record a supernova, which we know today as SN 185. In 2006, NASA's Chandra and XMM-Newton X-ray observatories imaged a remnant called RCW 86, a vast shell of gas seemingly ejected by SN 185. It might have taken 2,000 years, but we're gradually becoming able to observe and understand these massive events like never before.

When we deal with measures of time in this article, it is worth bearing in mind the limitations of the speed of light. When SN 185 was first observed in 185 AD, those Chinese astronomers were actually observing an event that happened 8,200 years prior, as SN 185 is 8,200 light years away. Of course, when the light finally reaches us we are able to observe the events in their entirety, but it is important to realise that these are cosmic occurrences that happened long in the past, from thousands of years to billions in some instances.

That doesn't take away from the scientific merit of observing them, however. They might be snapshots into the universe's past but they still hold key information into stellar life cycles and the regeneration of the cosmos. In fact, supernovas are thought to be among the most important events in the universe for a number of reasons. Before we tackle that, though, we need to understand the basics of how a supernova works.

At the heart of stars a process called fusion takes place, where light elements such as hydrogen and helium fuse together to form heavier elements, anything from carbon to iron to oxygen. The process of nuclear fusion releases a vast amount of energy in the form of many different types of radiation, including heat and visible light, both of which we directly observe and feel ourselves every day from the Sun. Stars are abundant in both hydrogen and helium, but their supplies are not endless. While it varies from star to star, eventually a star's source of fuel runs out. In most cases the predominant element left at the star's core is iron, which no star is able to fuse. What happens next is simply astounding.

Eventually, so much iron will build up that the star can no longer support its own weight. Until this point, and indeed for the majority of a star's lifetime, the force of gravity pulling the star inwards is delicately balanced by the pressure of the star's gases radiating outwards. Once the fuel is gone, however, this pressure suddenly dissipates. In just a millisecond, the core (which is now rich in iron and more massive than the Sun) collapses in on itself, shrinking in size by up to a thousand times from the size of the Earth to a ball only about 20 kilometres (12 miles) across.

Incredibly, though, the collapse is so quick that the layers of gas surrounding the core don't have time to react. Just a split second later, before these layers have even had a chance to begin collapsing as well, the now ultra-dense iron-rich core explodes with more energy than a quantity of TNT the size of Earth being instantly detonated. The energy output of a supernova is similarly astounding.

In most cases a supernova will shine as bright as 10 billion suns, and it will release 10^{44} joules, which is roughly the total output of the Sun in its entire 10 billion year lifetime. The resultant shockwave can travel at velocities approaching half the speed of light, and it will continue expanding into the surrounding interstellar space for thousands of years. The rate of expansion is such that a supernova's effects can be felt tens or even hundreds of light years away. If you think that all stars meet this same explosive end, however, you'd be wrong.

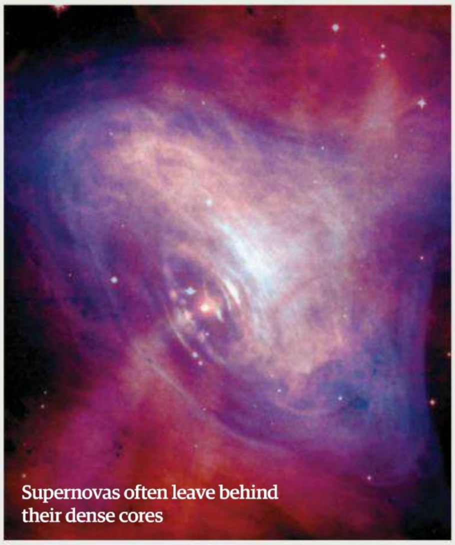
There are two main types of supernova: Type 1, or companion star supernovas, and Type II, or core collapse supernovas. The former typically occur in stars when their mass exceeds 1.4 solar masses, known as the Chandrasekhar limit, due to the accretion of matter in a binary star system with a white dwarf star, while the latter involve the collapse of stars between eight and 15 solar masses.

Both types are further sub-categorised to denote the particular characteristics of the supernova. The light of Type II-L supernovas steadily decreases after the explosion, whereas Type II-P supernovas emit light much more steadily. Type 1a supernovas involve a white dwarf and a larger star in a binary system, whereas Type 1b and 1c supernovas are more similar to the core collapse scenario, but they will have already lost most of their outer layers before the explosion.

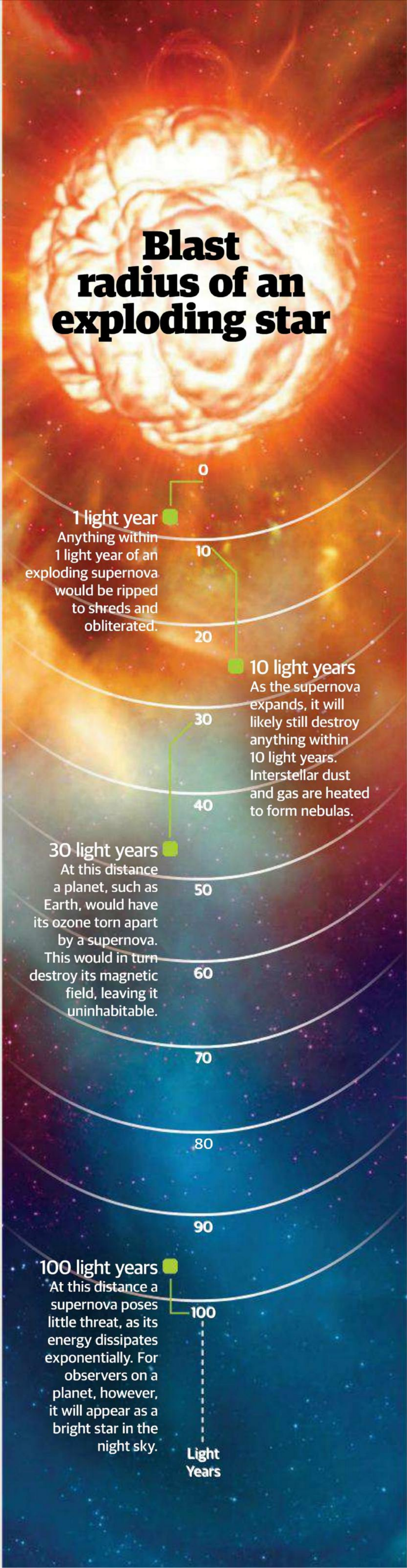
One of the few supernovas to be observed was SN 2008D in the spiral galaxy NGC 2770 back in early 2008. By chance, researchers using NASA's orbiting Swift telescope noticed an increase in X-rays from the star, and immediately alerted eight other ground and space telescopes to the event. The resulting blast lasted just five minutes, but the research will surely last a lifetime. The expansion rate was estimated at 10,000 kilometres (6,000 miles) per second, although one side of the star expanded faster than the other, suggesting that the explosion was off-centred.

The universe is abundant in hydrogen and helium but not so much in heavier elements such as carbon and oxygen, life-essential elements without which planets like Earth could not become habitable. The only place where these heavier elements are known to be made is in the very heart of stars, where they are stored until the star explodes as a supernova and scatters them into the surrounding space. Without supernovas, these elements would remain locked away, unable to contribute to the formation of metal-rich objects like planets and asteroids. It's very likely that planetary systems, like our own Solar System, were born in this way, from a cloud of dust and gas left behind after a star went supernova.

Another important consequence of supernovas is the formation of new stars. One of the oldest stars



Supernovas often leave behind their dense cores



Blast radius of an exploding star

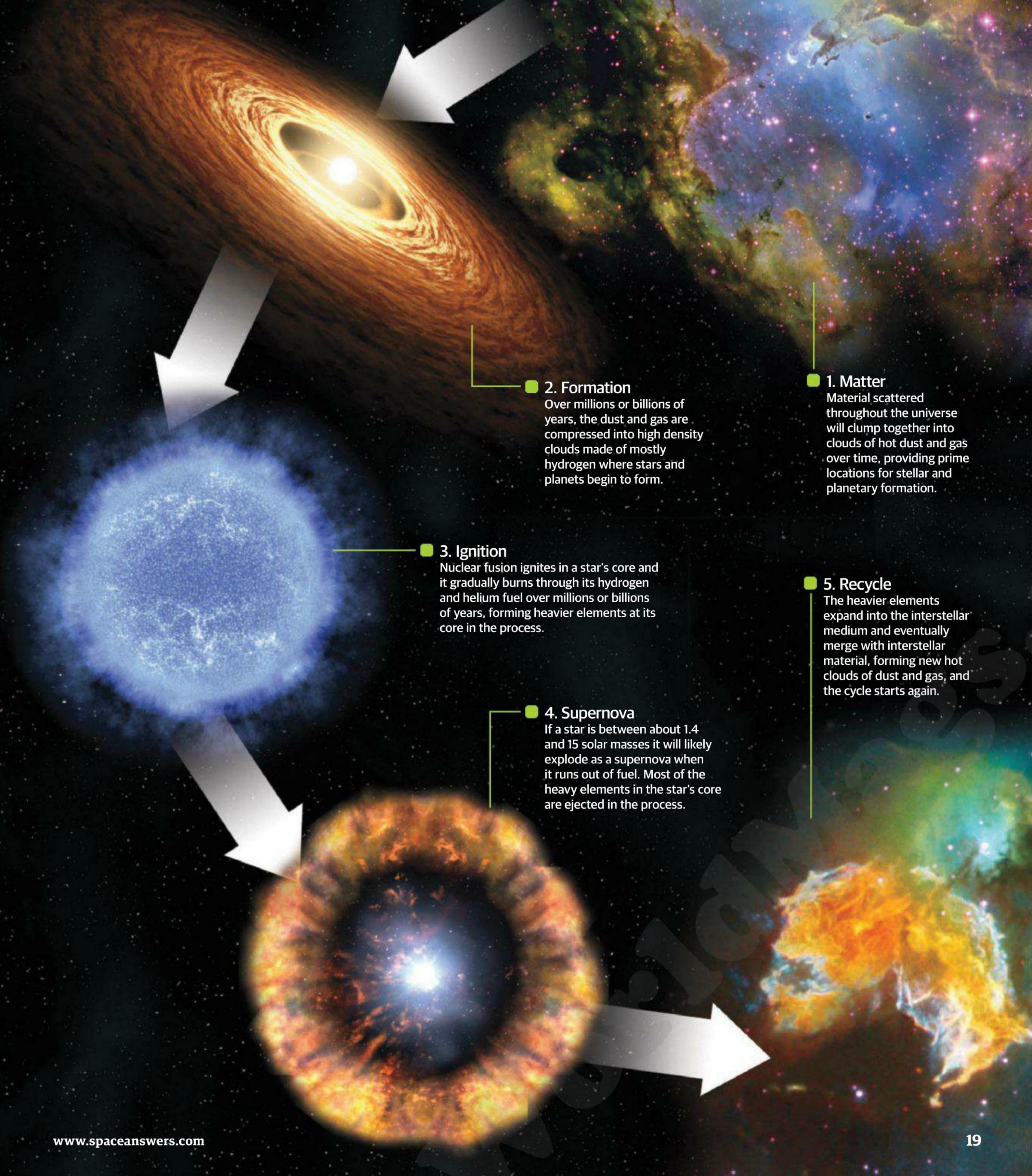
1 light year
Anything within 1 light year of an exploding supernova would be ripped to shreds and obliterated.

10 light years
As the supernova expands, it will likely still destroy anything within 10 light years. Interstellar dust and gas are heated to form nebulas.

30 light years
At this distance a planet, such as Earth, would have its ozone torn apart by a supernova. This would in turn destroy its magnetic field, leaving it uninhabitable.

100 light years
At this distance a supernova poses little threat, as its energy dissipates exponentially. For observers on a planet, however, it will appear as a bright star in the night sky.

Supernovas and the stellar cycle



1. Matter
Material scattered throughout the universe will clump together into clouds of hot dust and gas over time, providing prime locations for stellar and planetary formation.

2. Formation
Over millions or billions of years, the dust and gas are compressed into high density clouds made of mostly hydrogen where stars and planets begin to form.

3. Ignition
Nuclear fusion ignites in a star's core and it gradually burns through its hydrogen and helium fuel over millions or billions of years, forming heavier elements at its core in the process.

4. Supernova
If a star is between about 1.4 and 15 solar masses it will likely explode as a supernova when it runs out of fuel. Most of the heavy elements in the star's core are ejected in the process.

5. Recycle
The heavier elements expand into the interstellar medium and eventually merge with interstellar material, forming new hot clouds of dust and gas, and the cycle starts again.

that we know of is HE 1523-0901, a red giant star 7,500 light years from Earth. It was thought to have formed about 13.2 billion years ago, 500 million years after the estimated beginning of the universe. Clearly this means that most stars that we know of were formed after the Big Bang, in some cases (such as our own Sun) many billions of years after. The only way new stars could have been born was if older stars that survived from the birth of the universe eventually went supernova, releasing their various elements and eventually leading the way to the formation of new stars.

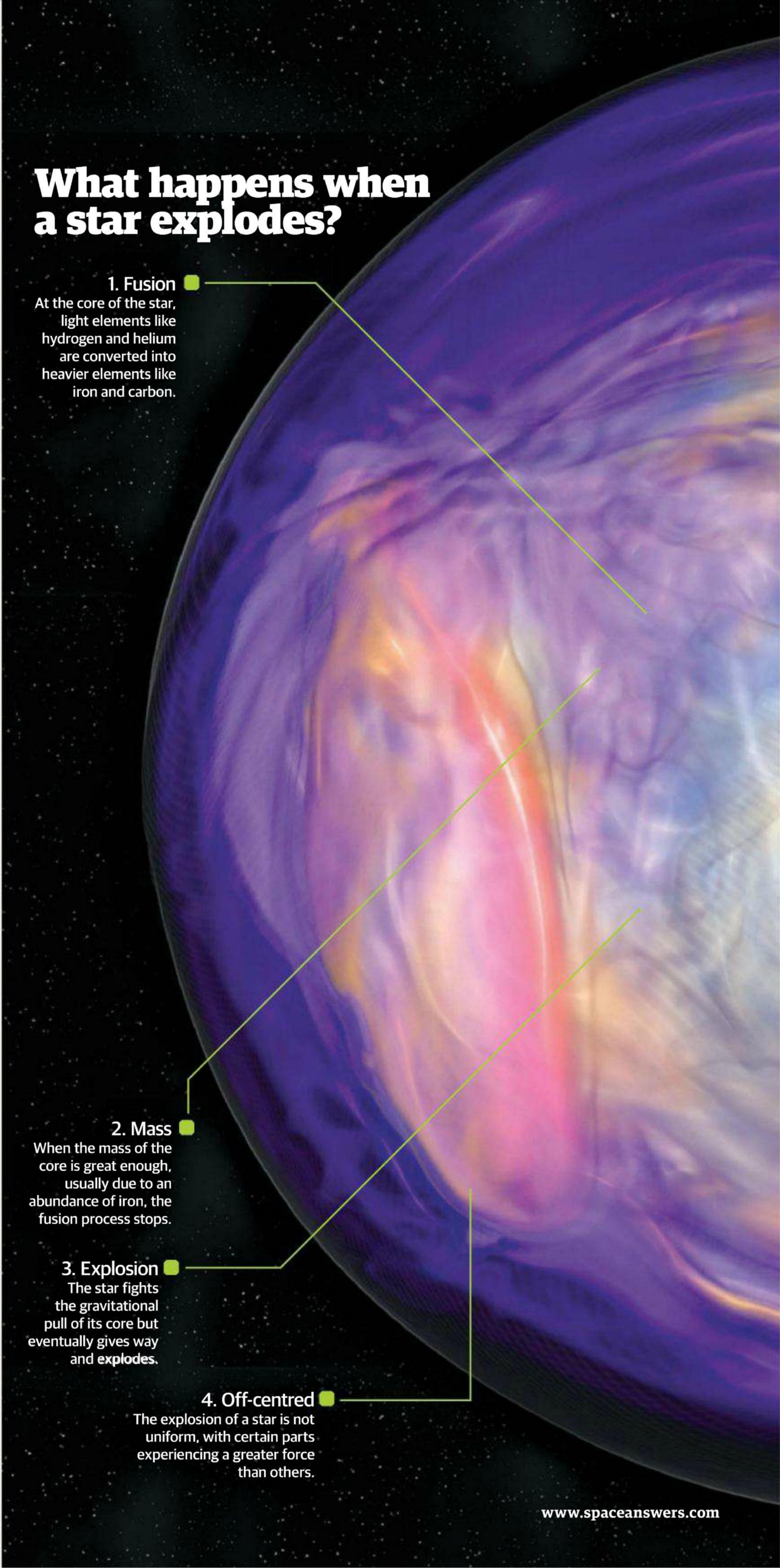
The final major contribution of supernovas to the universe is the continued addition of heavy elements to the interstellar medium. The gradual growth in abundance of these heavier elements, ones that were only found in traces before, has had an odd effect on some stars. Those like our own Sun undergo a somewhat different fusion process to those stars born nearer the start of the universe, as the former are moderated more by the presence of carbon. It is likely that future stars will continue to be altered by the presence of more heavy elements, further altering the fusion process within stars.

So, it's safe to say that supernovas are really quite important, but how do we know so much about them? After all, we've only observed very few, instead normally catching only the aftermath or the resultant remnant. Well, fortunately by observing the aftermath we're able to discern a lot about the explosion itself. For one thing, most Type 1a supernovas seem to undergo very similar final moments. If we see one explode we are able to calculate how far away it is thanks to something known as the "standard candle" method, where all Type 1a explosions explode with pretty much the same magnitude. In addition, using spectroscopy, we can analyse the resultant remnant and, by observing its size and composition, we can work out what the original star might have been like.

Supernovas will continue to be one of the most fascinating and exhilarating events in the universe, providing us with a view into stellar formation and the death of stars. It is thanks to these events that we know so much about the inner composition of stars, and by continuing to study them we will unearth more secrets of the universe. ●

What is a remnant?

A supernova remnant is the expansion of the blast wave from the supernova as it moves through space, pushing material out along with it that we can observe in different wavelengths from Earth. The expansion rate of a remnant can be up to several thousand kilometres per second, approaching 1% the speed of light, and it may continue for hundreds or thousands of years. Many nebulas we can see from earth are the result of the expansion of supernova remnants, and they can often measure several hundred light years across.



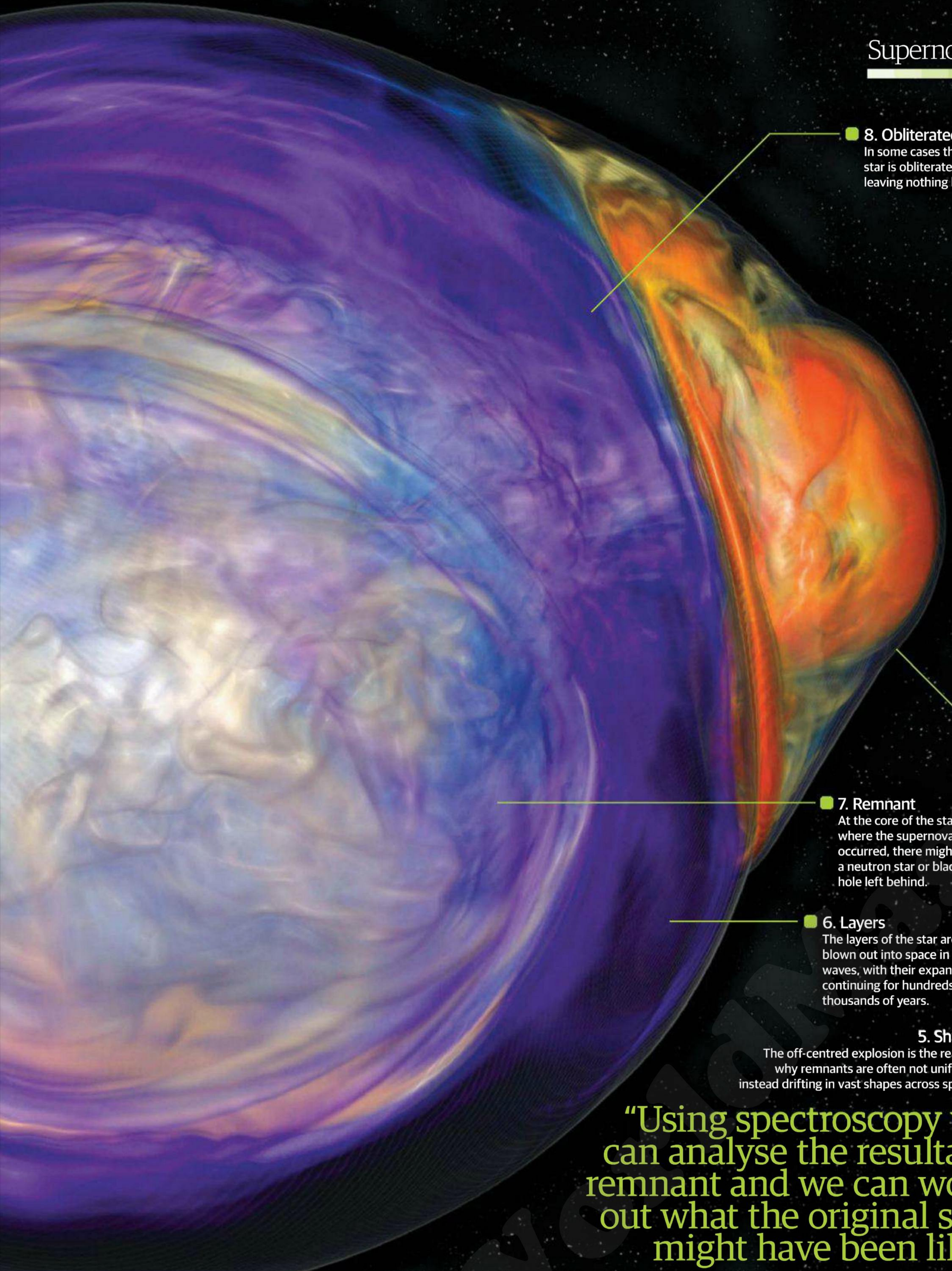
What happens when a star explodes?

1. Fusion
At the core of the star, light elements like hydrogen and helium are converted into heavier elements like iron and carbon.

2. Mass
When the mass of the core is great enough, usually due to an abundance of iron, the fusion process stops.

3. Explosion
The star fights the gravitational pull of its core but eventually gives way and explodes.

4. Off-centred
The explosion of a star is not uniform, with certain parts experiencing a greater force than others.



8. Obliterated
In some cases the entire star is obliterated, leaving nothing behind.

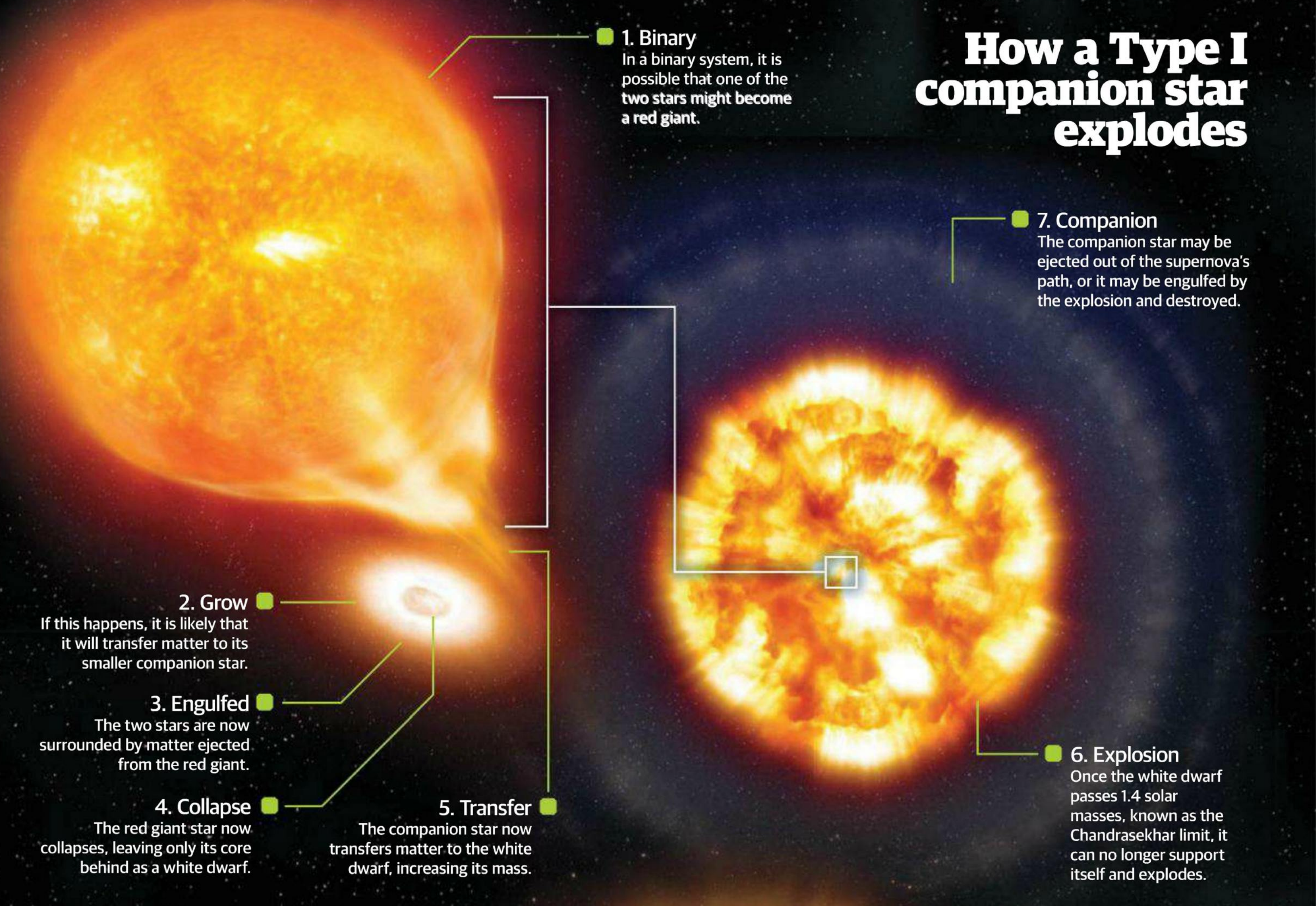
7. Remnant
At the core of the star where the supernova occurred, there might be a neutron star or black hole left behind.

6. Layers
The layers of the star are blown out into space in waves, with their expansion continuing for hundreds or thousands of years.

5. Shape
The off-centred explosion is the reason why remnants are often not uniform, instead drifting in vast shapes across space.

> “Using spectroscopy we can analyse the resultant remnant and we can work out what the original star might have been like”

How a Type I companion star explodes



1. Binary
In a binary system, it is possible that one of the two stars might become a red giant.

2. Grow
If this happens, it is likely that it will transfer matter to its smaller companion star.

3. Engulfed
The two stars are now surrounded by matter ejected from the red giant.

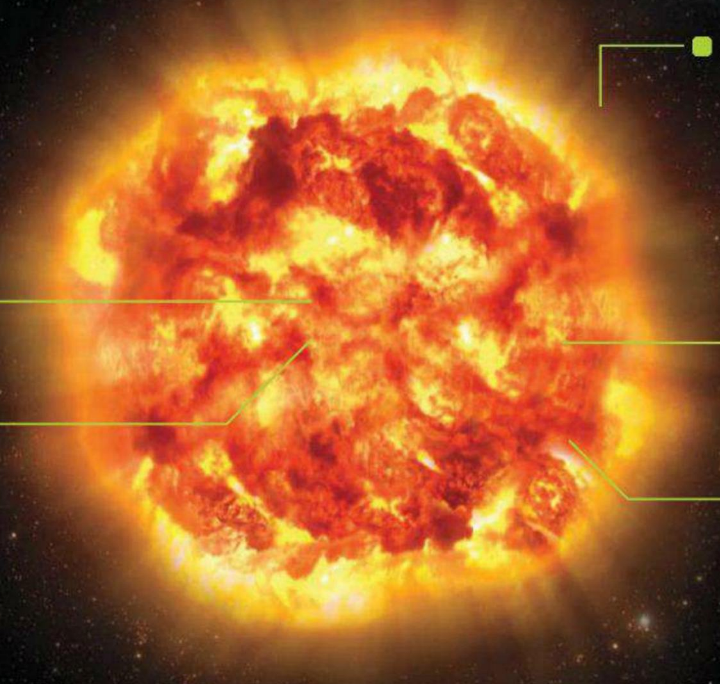
4. Collapse
The red giant star now collapses, leaving only its core behind as a white dwarf.

5. Transfer
The companion star now transfers matter to the white dwarf, increasing its mass.

6. Explosion
Once the white dwarf passes 1.4 solar masses, known as the Chandrasekhar limit, it can no longer support itself and explodes.

7. Companion
The companion star may be ejected out of the supernova's path, or it may be engulfed by the explosion and destroyed.

What happens in a Type II core collapse



1. Core
A star's iron core collapses under the force of gravity as it runs out of fuel.

2. Density
When the density of the core exceeds that of the surrounding matter, the core starts sending out waves of pressure.

3. Shock waves
The pressure waves rebound off material falling towards the core, sending shockwaves back into the centre of the star.

4. Energy
At first, the waves are unable to overcome the force of the outgoing pressure waves and thus cannot reach the surface of the core.

5. Explosion
Eventually, the build-up of shockwaves overcomes the pressure waves, and the surface of the core is impacted and, subsequently, explodes.

Most spectacular supernovas

Crab Nebula

Exploded: 7,500 years ago
Distance: 6,500 light years

This famous supernova remnant has a rapidly rotating star known as the Crab Pulsar at its centre, left behind after the original star exploded. This nebula is now 11 light years across but is still expanding at a rate of 1,500 km (930 miles) per second, 0.5% the speed of light. It is part of the Perseus Arm of the Milky Way Galaxy and the nebula is also referred to as Messier 1 or M1, being the first Messier Object catalogued in 1758. The explosion of the supernova that created this nebula, SN 1054, was recorded around the world in 1054 AD.

Kepler's Supernova

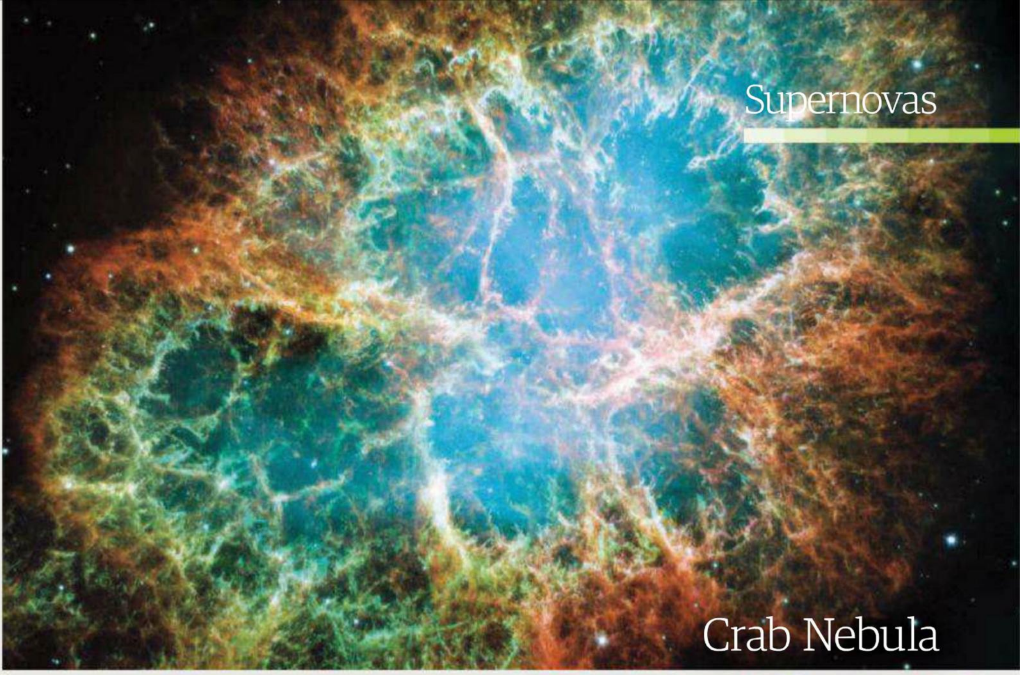
Exploded: 24,000 years ago
Distance: 20,000 light years

Observed by astronomer Johannes Kepler in October 1604, hence the name, Kepler's Supernova (SN 1604) is the most recent stellar explosion that was visible to the naked eye on Earth, although evidence exists for a Milky Way supernova whose signal would have reached earth around 1868, but was not visible to the unaided human eye. Kepler's Supernova was brighter in the night sky for three weeks than any other star or planet, except for the Sun and Venus, and could even be seen during the day.

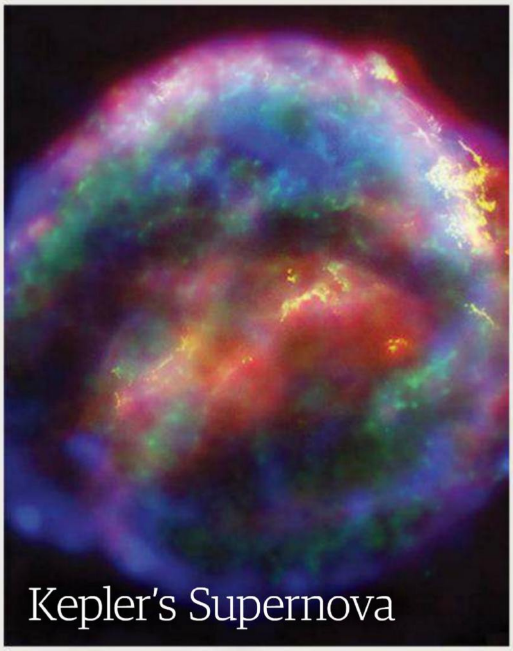
RCW 86

Exploded: 11,000 years ago
Distance: 9,100 light years

This supernova remnant is thought to be that left behind after star SN 185 blew up in 185 AD. It was recorded by Chinese astronomers and remained visible for some eight weeks. Recent X-ray studies show a good match for this estimated age. As such, RCW 86 is the oldest recorded supernova, and was thought to be a companion star supernova. The remnant is bigger than scientists would expect from such a supernova, suggesting the initial dwarf star created a 'cavity' in space before it exploded into which ejected material could quickly traverse.



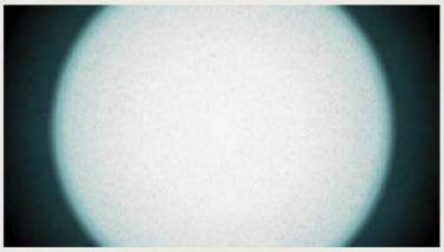
Crab Nebula



Kepler's Supernova

RCW 86

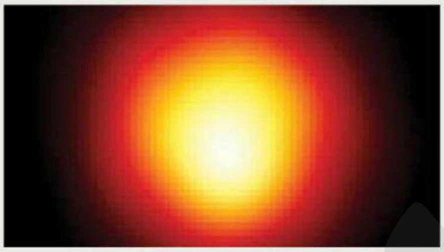
Coming soon to a galaxy near you...



IK Pegasi

Will explode: 5 million years from now
Distance: 150 light years

IK Pegasi A is expected to evolve into a red giant, which will transfer matter to the smaller IK Pegasi B white dwarf star and cause it to explode in a Type 1a supernova. IK Pegasi is moving away, so while it is currently the closest star to us that can go supernova, when it does in a few million years it will no longer be.



Betelgeuse

Will explode: 0 to 1 million years from now
Distance: 640 light years

Currently in the later stages of its life, it is expected to explode as a Type II supernova within the next million years, although it could explode at any minute. The star is a red supergiant and is less than ten million years old, a miniscule amount in astronomical terms, and thus it has passed through its life rapidly.

Antares

Will explode: 0 to 1 million years from now
Distance: 550 light years

The red supergiant Antares has a companion star, Antares B, that is thought will contribute to a Type 1a supernova event in the coming years. However, the exact timing of the supernova is unknown. Antares is more than 880 times bigger than our Sun and thus the explosion is expected to be quite an event.

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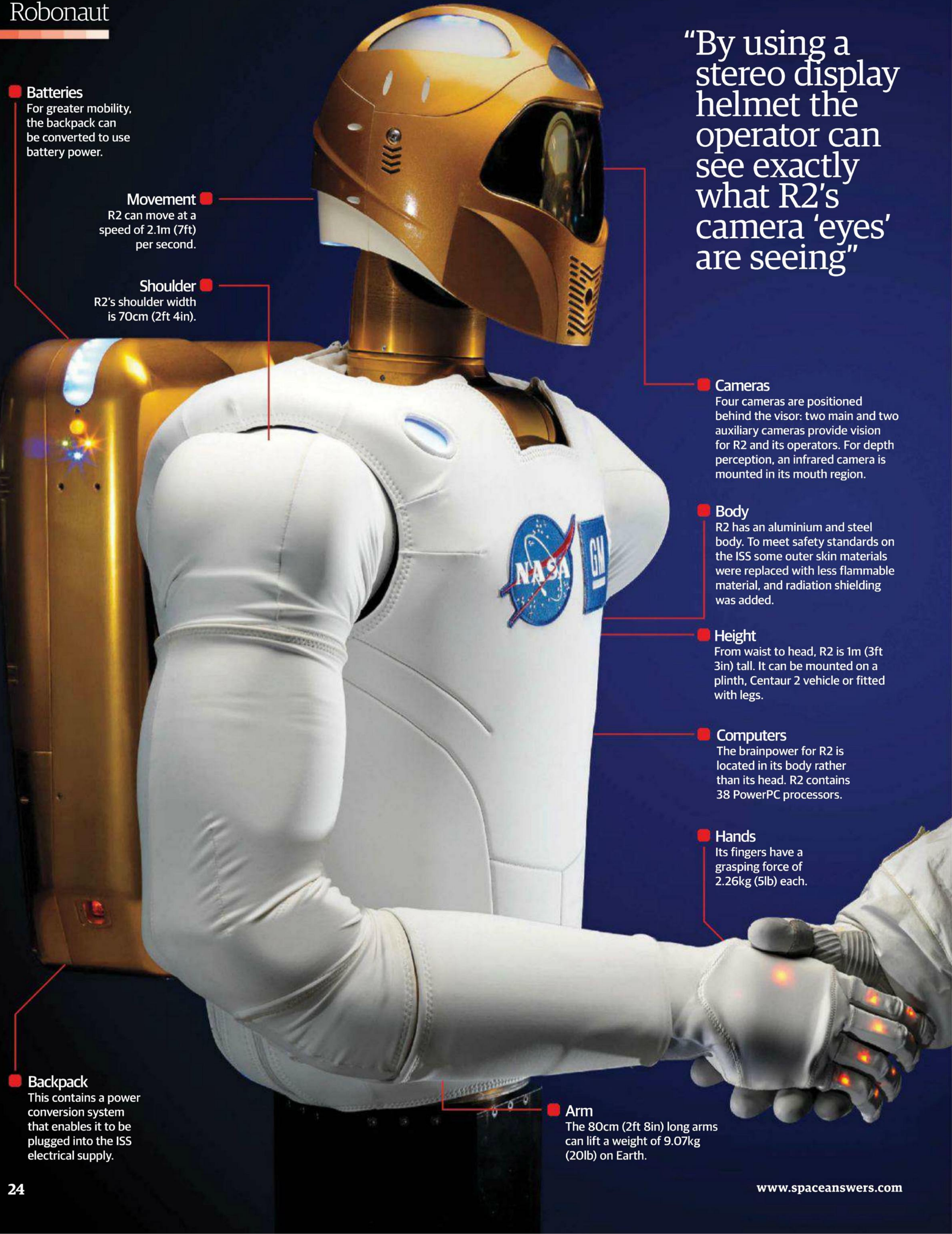


“By using a stereo display helmet the operator can see exactly what R2’s camera ‘eyes’ are seeing”

Batteries
For greater mobility, the backpack can be converted to use battery power.

Movement
R2 can move at a speed of 2.1m (7ft) per second.

Shoulder
R2’s shoulder width is 70cm (2ft 4in).

Backpack
This contains a power conversion system that enables it to be plugged into the ISS electrical supply.

Arm
The 80cm (2ft 8in) long arms can lift a weight of 9.07kg (20lb) on Earth.

Cameras
Four cameras are positioned behind the visor: two main and two auxiliary cameras provide vision for R2 and its operators. For depth perception, an infrared camera is mounted in its mouth region.

Body
R2 has an aluminium and steel body. To meet safety standards on the ISS some outer skin materials were replaced with less flammable material, and radiation shielding was added.

Height
From waist to head, R2 is 1m (3ft 3in) tall. It can be mounted on a plinth, Centaur 2 vehicle or fitted with legs.

Computers
The brainpower for R2 is located in its body rather than its head. R2 contains 38 PowerPC processors.

Hands
Its fingers have a grasping force of 2.26kg (5lb) each.

Meet the Robonaut

Robonaut is a NASA-led project to create a human-like robot to carry out dangerous tasks in outer space

NASA has many types of robot vehicles and robotic equipment, but the task given to its Robot Systems Technology Branch in 1997 was to create a robot that could work alongside human astronauts.

With the construction of the International Space Station (ISS), there was a need for regular extra-vehicular activity (EVA or spacewalks) to maintain and service the station, which could only be fulfilled by a mobile human astronaut. Most of these tasks are essential and dangerous, yet dull and do not require a lot of brainpower. For example, every 90 days one of the ISS crew has to hold a gauge in front of five airflow vents scattered throughout the station to check whether they're working correctly or not. A robot is perfect for this task because it does not breathe, whereas human breathing can contaminate the results, and it can hold the gauge more steadily in the microgravity environment.

In 2000, the outcome of this project was Robonaut 1. It had a head, torso and two arms with dextrous hands. Ten years of development in conjunction with General Motors produced Robonaut 2 (R2). Each R2 costs $2.5 million (£1.5 million) and weighs 150 kilograms (330 pounds). It is essentially the same as R1 but has better dexterity, speed of movement and sensing abilities.

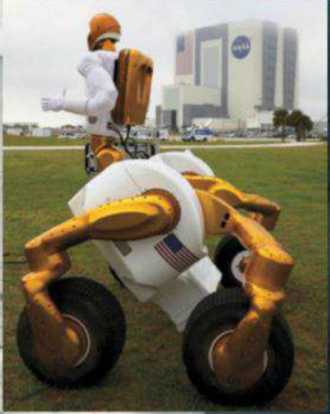
R2's hands consist of two sections that allow it to manipulate and grasp objects. 14 motors and 12 circuit boards inside its 20cm (8-inch) long, 10cm (4-inch) diameter forearms control the hands. The head contains five cameras: four provide stereo vision and one infrared camera offers depth of perception.

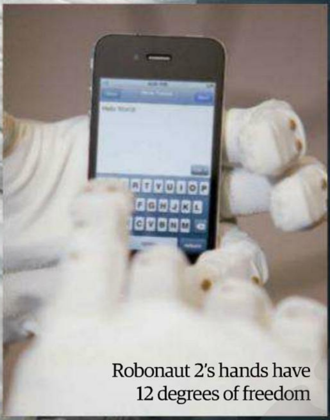
Robonaut can be given simple jobs to do and its computers can work out how to do them, or it can be operated from Earth. By using a stereo display helmet the operator can see exactly what R2's camera 'eyes' are seeing and sensors on the operator's hands and body can be duplicated by R2 to move and manipulate objects.

On Earth, Robonaut can be mounted on a four-wheel Centaur 2 rough terrain vehicle platform that is also suitable for use on the surface of other planets. When R2 was sent to the ISS in 2011, it was unpacked and mounted on a plinth, though there are plans for legs to be fitted to it to help it move around the station.

In future, Robonauts with better body protection and mobility could work outside the International Space Station and even service other satellites and take part in missions to the Moon or Mars.

Robonaut 2 can be mounted on a number of different bases





Robonaut 2's hands have 12 degrees of freedom

Robots in space

Space probes

Even the earliest space probes had robotic pre-programmed systems to keep them operational. Today, probes like the Cassini spacecraft need robotic systems as they are so far from mission control on Earth.

Remotely operated vehicles

The Curiosity rover is the latest example of a robot vehicle sent to explore the surface of another planet. It used pre-programmed computer software for the descent and landing.

Remote Manipulator System

This robotic arm system was fitted to the Space Shuttle and ISS. Astronauts can use it to deploy or gather payloads. For more delicate jobs a grappling hand can be used.

Celestial Witch's Broom

This stunning photo from the ESO highlights a magical feature in the Pencil Nebula

These two images, taken by the European Southern Observatory's La Silla Observatory in Chile, show a peculiar cloud of gas 800 light years away in the Vela constellation known as the Pencil Nebula (or NGC 2736).

The Pencil Nebula is a cloud of glowing gas left behind after a supernova explosion 11,000 years ago. It is only a portion of the entire supernova remnant, but it is the brightest region. The peculiar shape of this cosmic structure has earned it the moniker of the 'Witch's Broom' as the glowing filaments resemble the strands on a broom.

The whole remnant is known as the Vela supernova remnant, a giant expanding shell of gas from the initial explosion that moved at millions of kilometres per hour when it first formed. Having moved through the gas between stars, the expanding shell is now slowing down with certain regions of it glowing brighter than others, such as the Pencil Nebula imaged here.

The brightest regions of the Pencil Nebula are areas where the supernova's shock waves have hit dense regions of interstellar gas, at one point heating the gas to millions of degrees. The gas is now cooling down but it continues to give off a faint glow. The blue areas of the nebula are the hottest, full of ionised oxygen atoms, whereas the red regions are cooler and emit hydrogen.

The Pencil Nebula is 0.75 light years across and expanding at a 'leisurely' 650,000 kilometres per hour (400,000 miles per hour), about 0.06% the speed of light. Such is the rate of its expansion that within a human generation it will move to a different position in the night sky.

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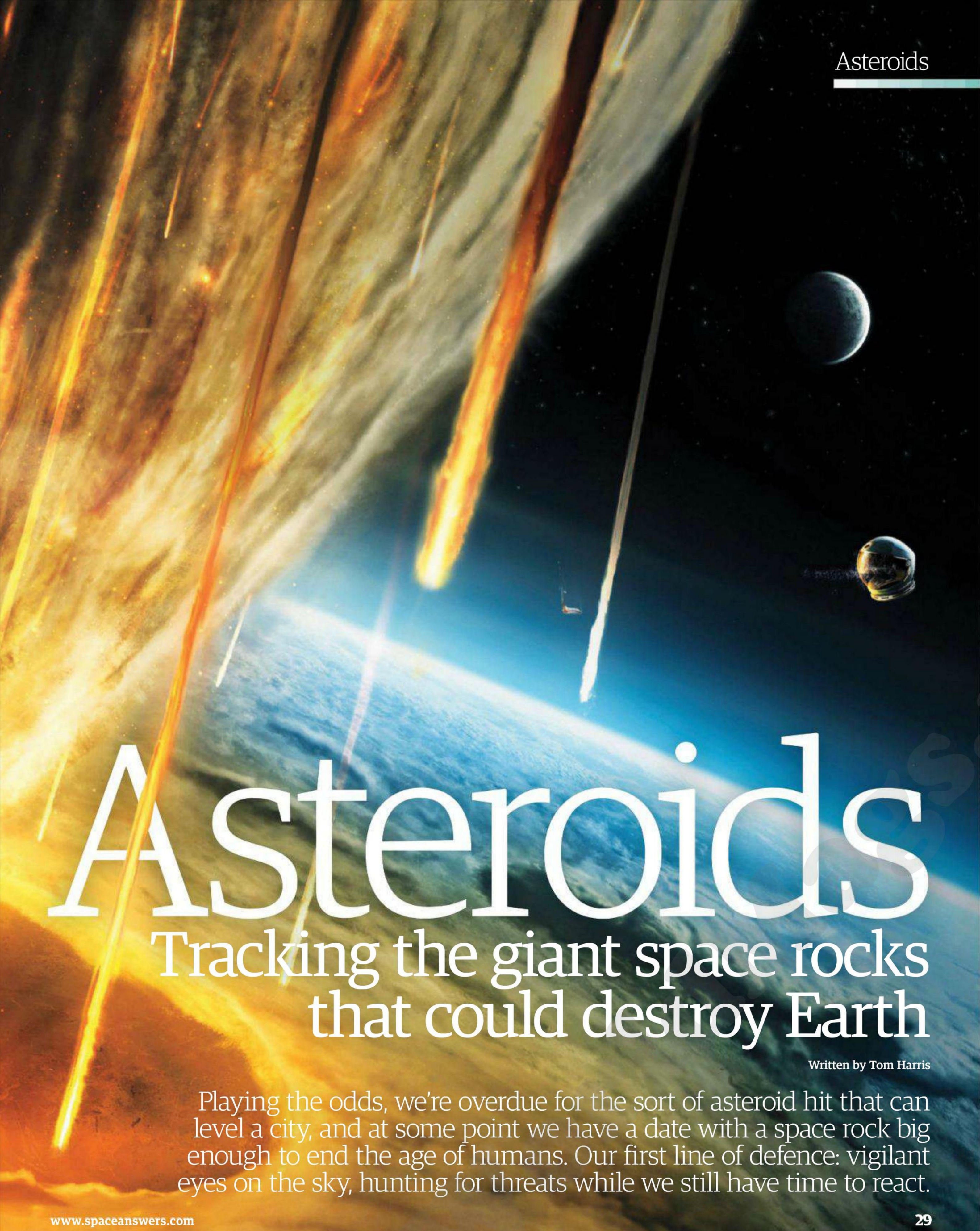


Asteroids

Tracking the giant space rocks that could destroy Earth

Written by Tom Harris

Playing the odds, we're overdue for the sort of asteroid hit that can level a city, and at some point we have a date with a space rock big enough to end the age of humans. Our first line of defence: vigilant eyes on the sky, hunting for threats while we still have time to react.

Dr Don Yeomans and his Near-Earth Object (NEO) Program are responsible for tracking the asteroids that could potentially threaten the Earth

The unsung heroes are a small team of astronomers who scour the night sky for near-Earth objects (NEOs), asteroids and comets that are headed for our neighbourhood. "There are probably a couple dozen folks who are doing this more or less on a full-time basis," explains the manager of NASA's Near-Earth Object Program Office, Dr Don Yeomans. "The vast majority of discoveries are made in the US Southwest and Hawaii, by NASA-supported telescope facilities."

The searchers have been enormously successful, cataloguing more than 9,000 NEOs – objects projected to travel within 1.3 astronomical units of the Sun (195 million kilometres, or 121 million miles). Smaller ones do still sneak up on us, though.

"That happens all the time," Yeomans says. "We had an object about the size of a small or fairly good-sized automobile that actually hit in October 2008. It was discovered about 24 hours in advance. We predicted it would impact over northern Sudan, and it did. It was observed by a KLM airline pilot and somebody with a cell phone camera on the ground. Astronomers actually went over there and looked for fragments of the asteroid and they found several."

Far from a catastrophe, the impact turned out to be an exceptional stroke of luck. "That was a scientific bonanza," Yeomans says. "They can examine these fragments in Earth-based laboratories to find out exactly what the chemical composition is, and they also had observations of this object in space, so they know its spectral characteristics. They could say, all right, this particular type of asteroid is made up of this chemical composition."

On top of identifying planetary threats ahead of time, this is a key benefit of tracking NEOs. "That's sort of the holy grail of asteroid science: to try and take the meteorites that we have in museums and have been studied to death in terms of the composition – chemical and elemental composition – and say, 'All right, this meteorite is an example of that type of asteroid in the sky.'"

There's no shortage of errant debris in the Solar System, left over from its earliest days as a massive cloud of gas and dust. Beginning about 4.6 billion years ago, much of this dust clumped together, forming larger chunks of matter. Many of these chunks, in turn, steadily formed planets and moons. But a lot never joined the big leagues. In fact, about 100 tons of the stuff shows up at Earth's door every day. Fortunately, almost all of it is sand-sized particles that burn up on contact with our atmosphere. There are plenty of bigger pieces out there, though. Most are found in a belt between Mars and Jupiter. It's home to millions of asteroids – chunks of rocky, metallic or carbon-based material. There are even more of their smaller counterparts, meteoroids. Some think Jupiter's gravitational pull has kept the debris in place, preventing it from coalescing into a planet.

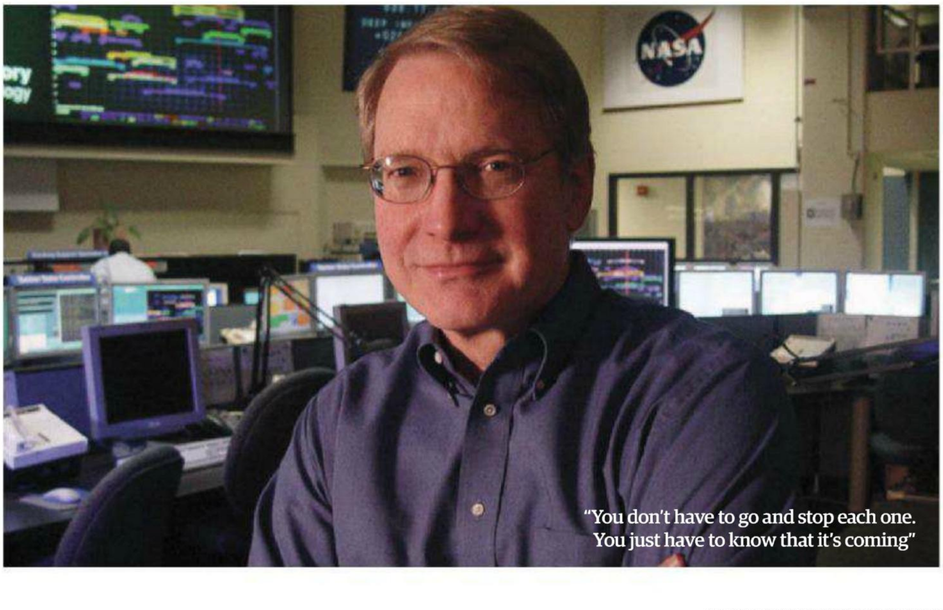
For the most part, these asteroids stay within the belt, revolving around the Sun in an orderly fashion. But now and then, a collision or a gravitational tug knocks an asteroid out of its orbit, into a path that takes it closer to the centre of the Solar System. A fraction of those end up heading our way.

Most of the asteroids that reach Earth come from the inner part of the belt, which is primarily made up of S-type asteroids, composed of silicate rock. We also encounter a good number of C-type asteroids, composed of carbon-rich material. The third variety, metallic M-type asteroids, are rare.

It's a similar story with comets, mixtures of dusty ice and rock that typically travel in the outer regions of the Solar System. The distinction between comets and asteroids is blurry, as some asteroids may contain ice, and comets may be fairly rocky. One of the chief distinctions is where you find them. Comets are concentrated in a region beyond Neptune and in a more distant comet concentration, called the Oort Cloud, about a light year from the Sun.

All told, there are potentially trillions of comets in the Solar System, though nearly all will never get anywhere near us. They stick to their wide orbits, the most distant potentially taking 30 million years for a single trip around the Sun. But, just as with asteroids, chance collisions and gravitational tugs occasionally set a comet into an orbit that takes it through the centre of the Solar System. Fortunately, comets' tails – streams of icy gaseous material vaporised by the Sun's heat – make them easier to spot. For instance, when the Hale-Bopp comet gets close to the Sun, it grows a tail spanning millions of kilometres. Comets and asteroids have played a critical role in our history

"If we detect a larger threat – the sort that could devastate a wide area or wipe out humanity – we'll need to alter its path"



"You don't have to go and stop each one. You just have to know that it's coming" as a species. In fact, we most likely owe our very existence to them, a few times over.

First, of course, our planet formed from asteroids colliding and clumping together. But beyond that, many scientists believe that comets delivered much of the water and carbon-based molecules that set the stage for the beginning of terrestrial life, 3.8 billion years ago. Flash forward to 65 million years ago, and a foreign object intervened again. A massive asteroid or comet collision brought about a rapid shift in our atmosphere that caused the extinction of about 75 per cent of life on Earth, including the dinosaurs. While it was surely no picnic for our mammalian ancestors either, the elimination of so many predators ultimately gave them a chance to thrive and evolve.

Asteroids and comets may play a critical role in our future, too, but the next hit isn't likely to be so beneficial to us. Scientists estimate the sort of impact that took out the dinosaurs – a collision with a comet or asteroid measuring ten kilometres (6.2 miles) or greater – comes along on average every 50-100 million years, but any day could be the day.

Objects measuring 30-100 metres (165-328 feet), big enough to cause substantial local damage or kick up tidal waves, hit every few hundred years or so. The last one was the Tunguska event, a massive explosion caused by an estimated 40-metre (132-foot), 80,000-ton asteroid fragment bursting over Siberia in 1908. It claimed no human casualties, but only because it happened to strike an uninhabited region. With an explosive energy about 500 times more powerful than the Hiroshima bomb, it cleared millions of trees across a 40-kilometre (25-mile) area and generated a shockwave powerful enough to shatter windows and knock people down many miles away. If it had hit a major city, the impact would have been the most devastating disaster in human history.

Fortunately, the odds are against such a hit. About 71 per cent of the Earth's surface is ocean, making the sea the most likely destination for an impact. On top of that, huge, uninhabited areas of land, such as Antarctica, increase our odds. Because of this, we've been blissfully unaware of most hits throughout human history. In this sense, the Tunguska event was a stroke of luck. It woke us up to the risks, spurring us to search the sky for potential dangers.

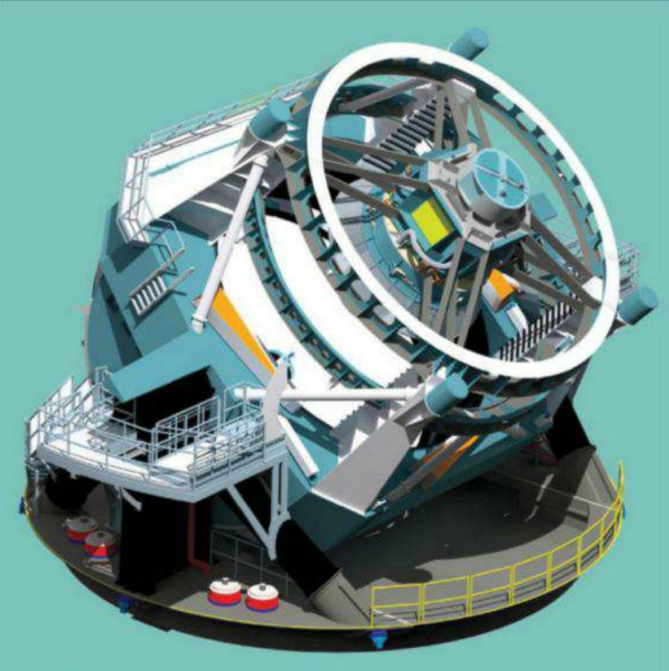
We've had other reminders since, including the first observation of a spectacular impact with a fellow planet. In 1994, the comet Shoemaker-Levy 9 collided with Jupiter, breaking up in its atmosphere into 21 fragments, some as large as two kilometres (1.25 miles) in diameter. On Earth, an impact of this calibre would have brought about global destruction.

NASA's main objective is identifying and tracking potentially hazardous asteroids (PHAs), defined as objects measuring at least 100 metres (328 feet) that have the potential to get within 0.05 astronomical units (about 4.7 million miles) of Earth.

The key equipment is a powerful telescope that captures detailed images of the night sky with a charge-coupled device (CCD), the same array of light-sensitive cells at the heart of a digital camera. But, Yeomans explains, successful asteroid and comet-hunting ultimately depends on something a little more low-tech: "Persistence."

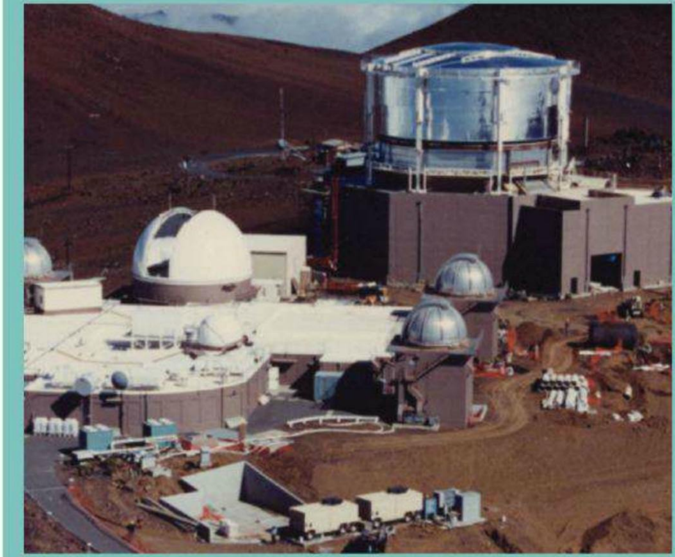
He describes a simple but painstaking process: "Basically, what they do is point their telescopes

Our eyes on the sky



The Large Synoptic Survey Telescope (LSST)

When it comes online, the 8.4-metre (27.5-foot) LSST in Chile will mark a substantial leap forward. It will combine a large aperture, a wide field of view, a 3-billion-pixel camera, and advanced data processing to monitor the night sky. It will be able to capture 800 panoramic images every night, covering the visible sky twice in a week.

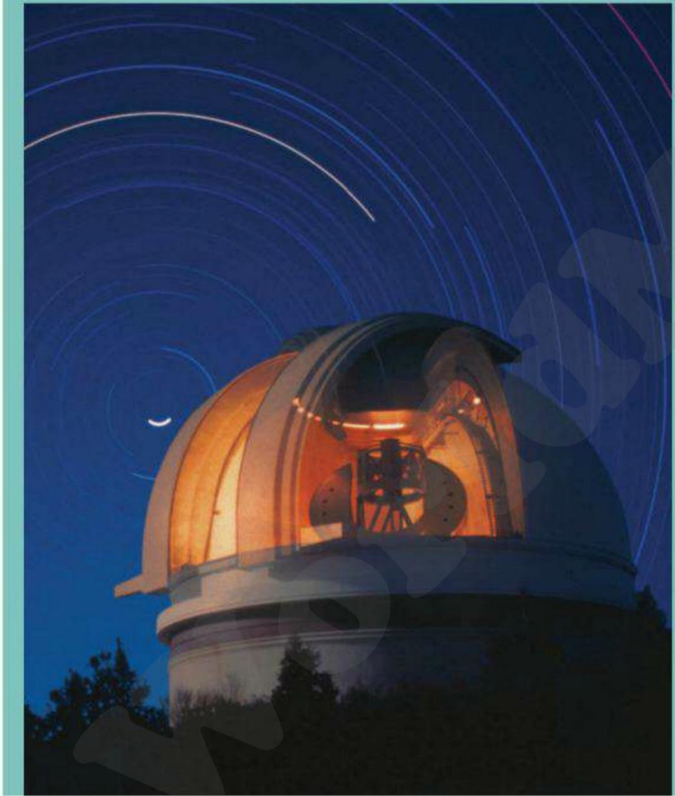


Maui Space Surveillance Site (MSSS)

The MSSS is part of a US Air Force satellite-tracking and research facility on Maui, Hawaii. It sits on the crest of Haleakala, an extinct volcano. The combination of minimal light pollution and a stable climate of dry, clean air gives the location exceptional year-round visibility.

In 2000, the Jet Propulsion Laboratory began using one of the two 1.2-metre (3.9-foot) telescopes to hunt for NEOs. To optimise the telescope for this, the US Air Force and JPL configured it for a larger field of view and installed a specialised camera.

In June, the MSSS team completed a modernisation of a range of equipment.

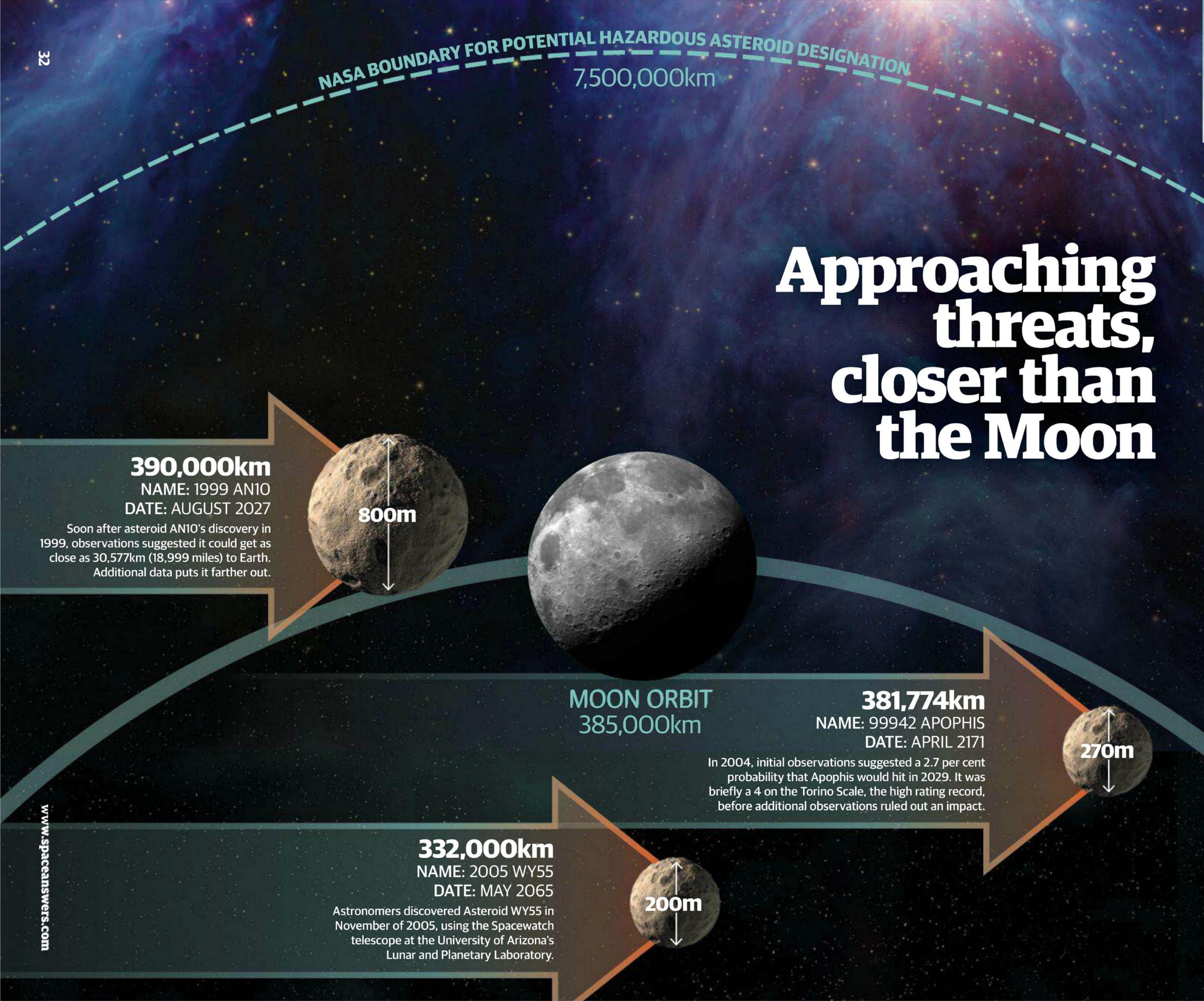


The Palomar Observatory

As a key observatory in the NASA Jet Propulsion Laboratory's NEO search programme going back to 1973, Palomar has been the site for thousands of discoveries, including hundreds of NEOs. The observatory is located in north San Diego county, California, and is owned and operated by the California Institute of Technology, which partners with JPL, Cornell, and many other institutions on a wide range of projects.

The observatory is home to five telescopes, including the 508-centimetre (200-inch) Hale, which was the world's largest telescope when it went into operation in 1947. The telescopes have seen regular upgrades, including a camera for NEO observations, the Near-Earth Asteroid Tracker, installed in 2001.

Approaching threats, closer than the Moon



390,000km
NAME: 1999 AN10
DATE: AUGUST 2027

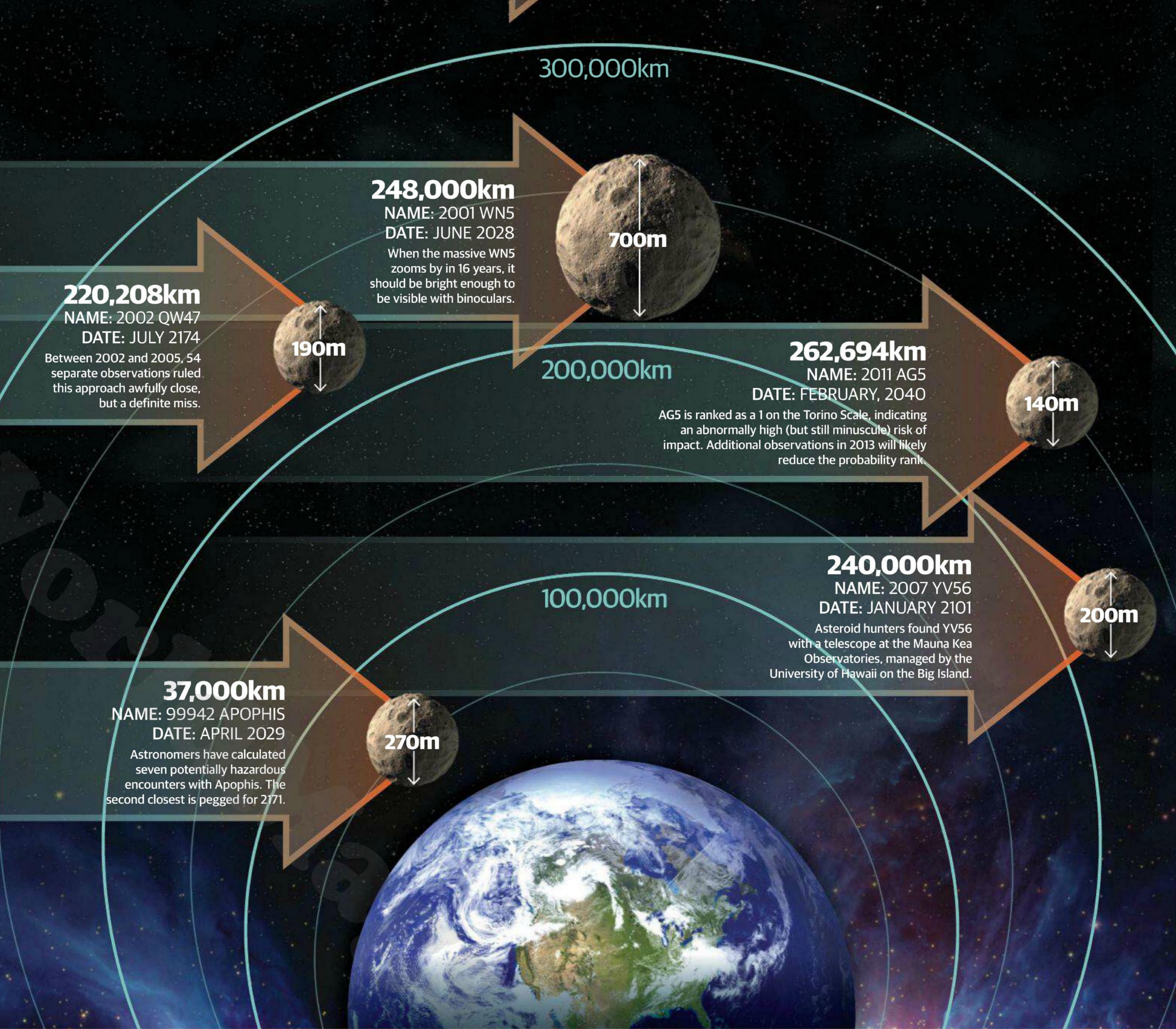
Soon after asteroid AN10's discovery in 1999, observations suggested it could get as close as 30,577km (18,999 miles) to Earth. Additional data puts it farther out.

381,774km
NAME: 99942 APOPHIS
DATE: APRIL 2171

In 2004, initial observations suggested a 2.7 per cent probability that Apophis would hit in 2029. It was briefly a 4 on the Torino Scale, the high rating record, before additional observations ruled out an impact.

332,000km
NAME: 2005 WY55
DATE: MAY 2065

Astronomers discovered Asteroid WY55 in November of 2005, using the Spacewatch telescope at the University of Arizona's Lunar and Planetary Laboratory.



248,000km
NAME: 2001 WN5
DATE: JUNE 2028

When the massive WN5 zooms by in 16 years, it should be bright enough to be visible with binoculars.

220,208km
NAME: 2002 QW47
DATE: JULY 2174

Between 2002 and 2005, 54 separate observations ruled this approach awfully close, but a definite miss.

262,694km
NAME: 2011 AG5
DATE: FEBRUARY, 2040

AG5 is ranked as a 1 on the Torino Scale, indicating an abnormally high (but still minuscule) risk of impact. Additional observations in 2013 will likely reduce the probability rank.

240,000km
NAME: 2007 YV56
DATE: JANUARY 2101

Asteroid hunters found YV56 with a telescope at the Mauna Kea Observatories, managed by the University of Hawaii on the Big Island.

37,000km
NAME: 99942 APOPHIS
DATE: APRIL 2029

Astronomers have calculated seven potentially hazardous encounters with Apophis. The second closest is pegged for 2171.

at a region of the dark sky and take a CCD image, come back to that same region 15 minutes later and take another image, come back to that same region 15 minutes later and take a third, or a fourth image. Then you can compare those three or four images to see if anything in the field has moved during the times that you took those images. The stars, of course, will remain stationary and will not have appeared to have moved, but any near-Earth asteroids will have appeared to move from one image to another, and the computers are good at picking up motions like that."

While it can be monotonous, computer technology has expedited the process immensely. Astronomers used to do it the hard way, examining two photographic plates under a microscope. "You would compare the images taken a few minutes apart one after the other, back and forth," Yeomans says. "The stars hadn't moved between when the two images were taken but the asteroid would have, so its image would appear to be hopping back and forth."

Today, computers make some of the discoveries themselves. Yeomans says the most successful search observatory today, the Catalina Sky Survey near Tuscon, Arizona, depends on close human-computer collaboration. "They routinely have the computer find candidates, and then a human observer looks at them to confirm that, in fact, the object that the computer picked was a near-Earth asteroid. So these computer programs, at least in this one case with the Catalina Sky Survey, don't actually completely replace humans. They simply make it easier for the humans to consider only the likely suspects."

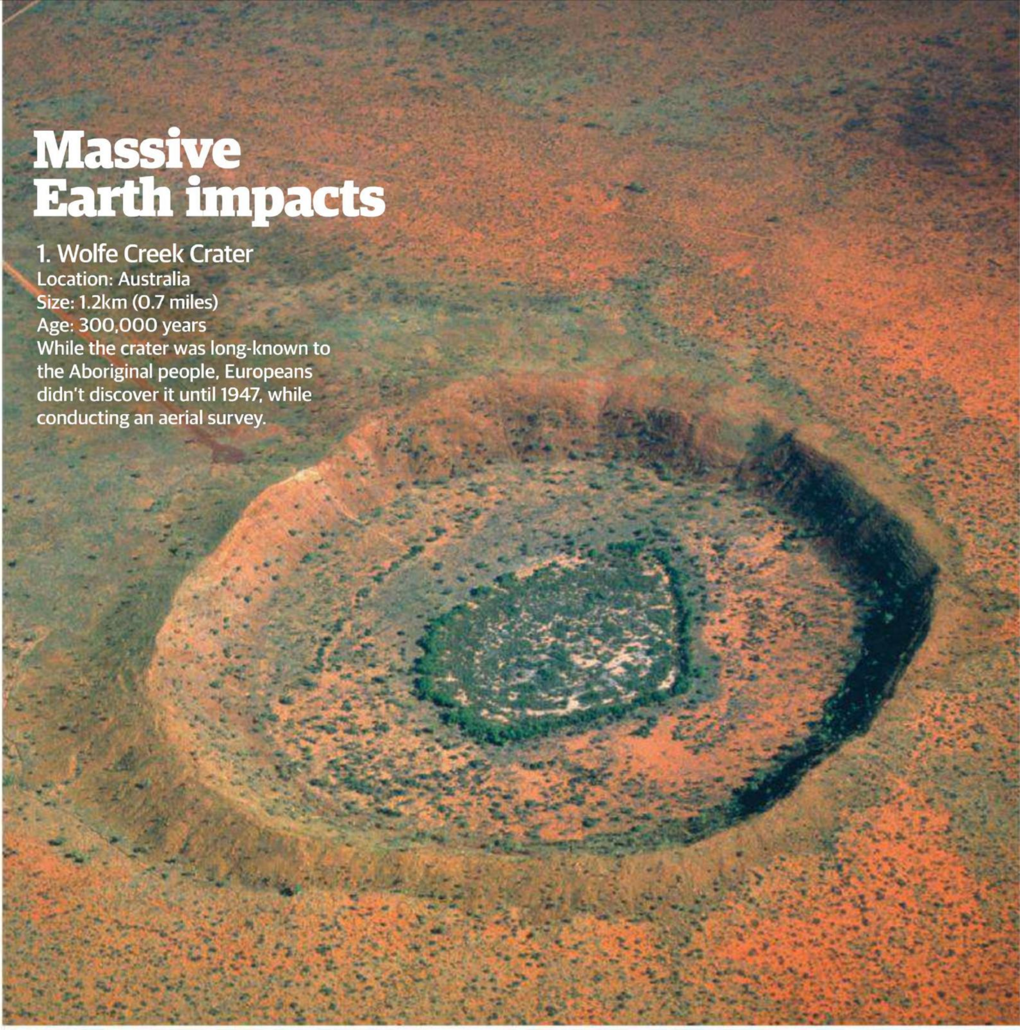
Yeomans says the key is getting high-fidelity images of large sections of the night sky: "Ideally, you would like to have a telescope with a large aperture, so you could collect a lot of light, and you'd have a wide field of view that covers a lot of sky. I think the perfect telescope would be one that went very deep to find faint objects and then at the same time covered a lot of sky so that you could cover a fair bit of the accessible sky every night."

Asteroid hunters have had to make do with less than perfect equipment, Yeomans says. "In fact, most of the telescopes that are currently being used were not built for the express purpose of finding near-Earth objects. So, they're one-metre class aperture – that is, their mirrors are usually one metre. There are a couple that are one and a half metres, 1.8 metres. But they weren't built with near-Earth object discovery in mind, so they're not all that wide field."

The NEO watch is getting a major upgrade with the Panoramic Survey Telescope & Rapid Response System (Pan-STARRS), a new telescope facility on top of the volcano Haleakala on the island of Maui. Designed with near-Earth object observation in mind, the system will boast 3-16 times the collecting power of other telescopes. A larger field of view will allow the system to scan the sky much more quickly, while massive CCD arrays will be able to pick up far fainter objects than other NEO survey telescopes. With 1.4 billion pixels apiece, the system's four cameras will be the largest in existence. Its prototype telescope, PS1, began regular survey operations in 2010. The finished four-telescope array will follow.

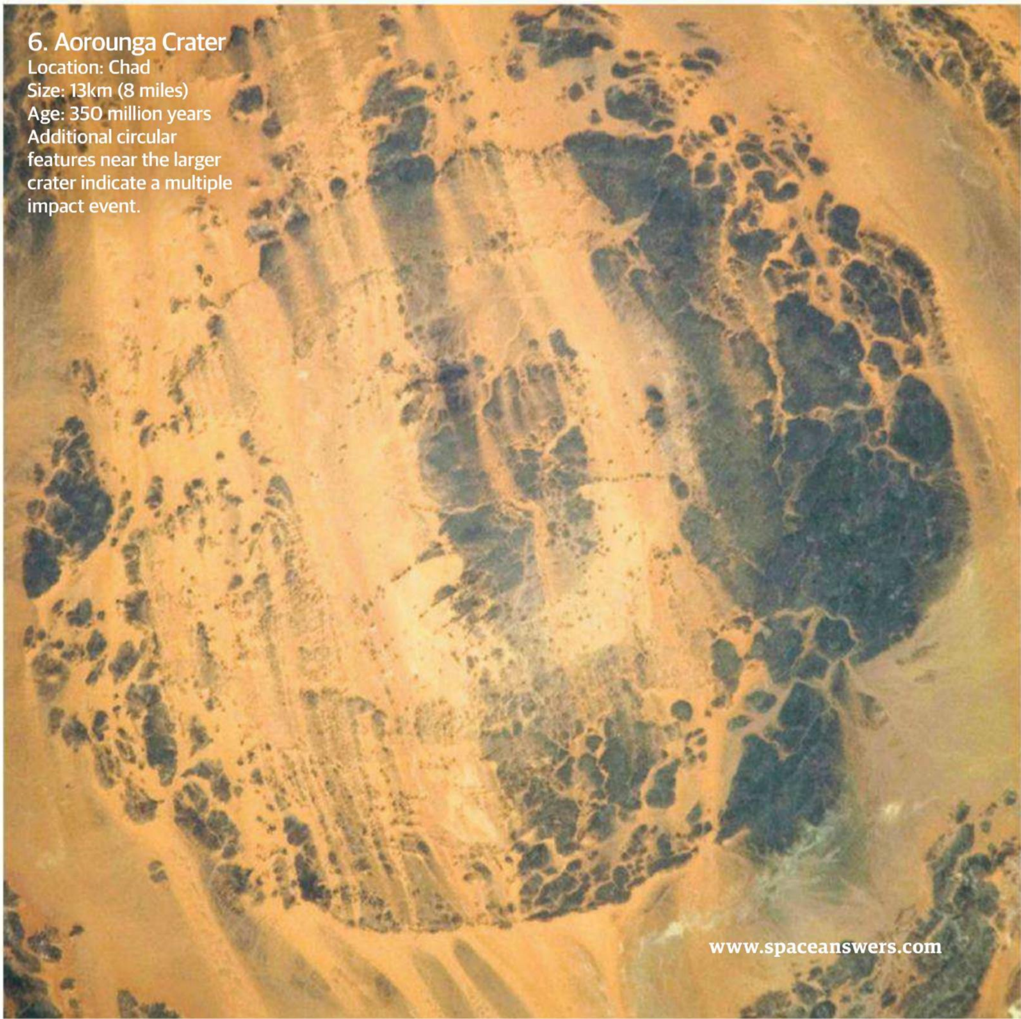
In the future, Yeomans is looking forward to the Large Synoptic Survey Telescope (LSST), a facility

Massive Earth impacts



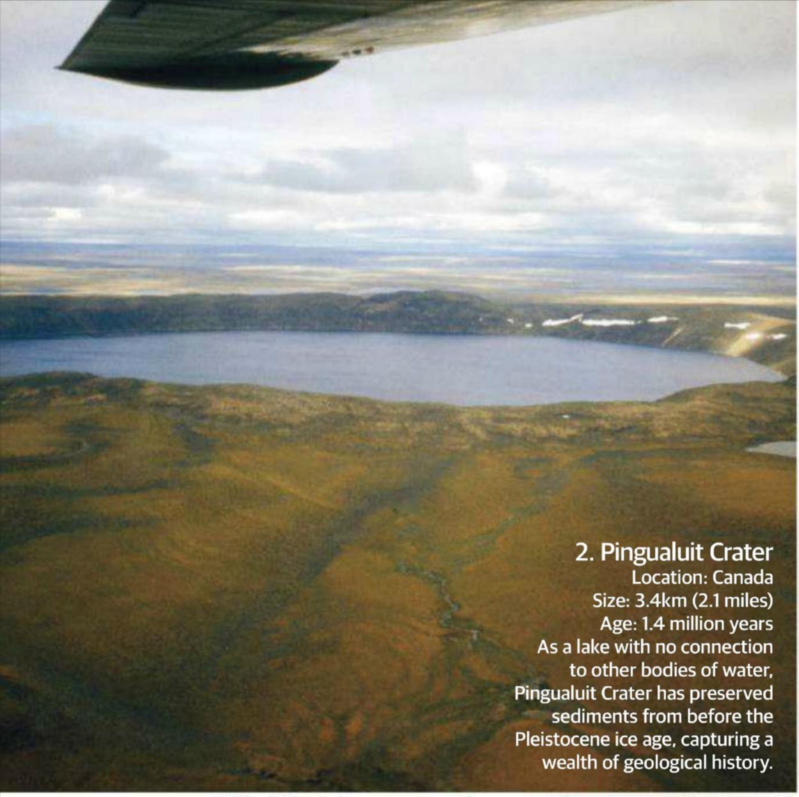
1. Wolfe Creek Crater

Location: Australia
Size: 1.2km (0.7 miles)
Age: 300,000 years
While the crater was long-known to the Aboriginal people, Europeans didn't discover it until 1947, while conducting an aerial survey.



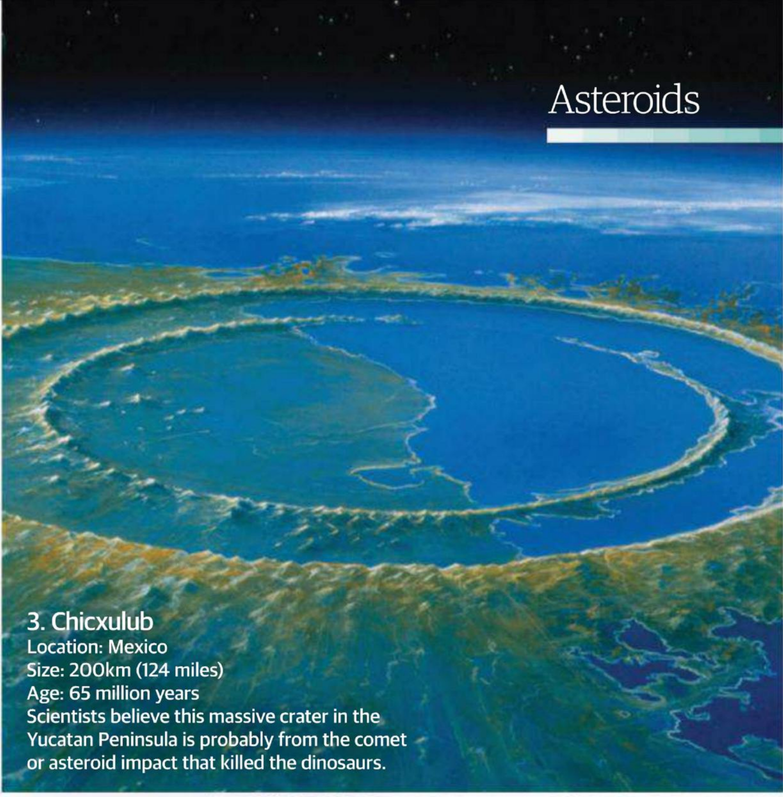
6. Aorounga Crater

Location: Chad
Size: 13km (8 miles)
Age: 350 million years
Additional circular features near the larger crater indicate a multiple impact event.



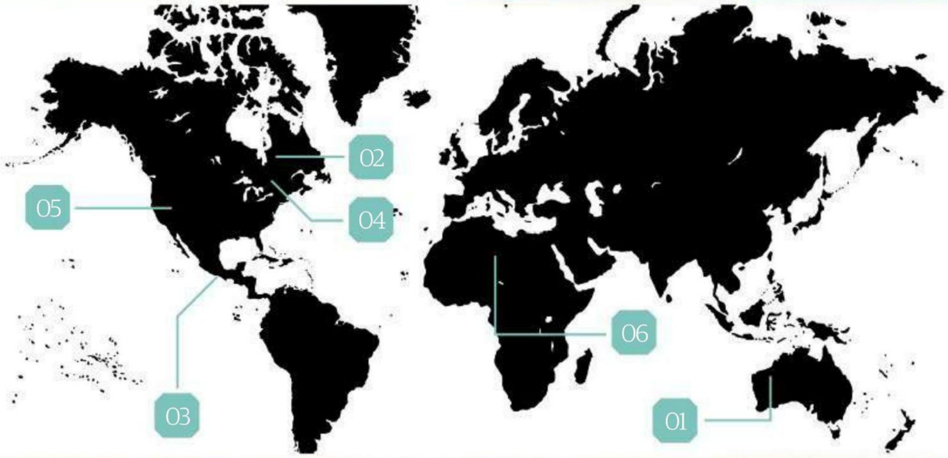
2. Pingualuit Crater

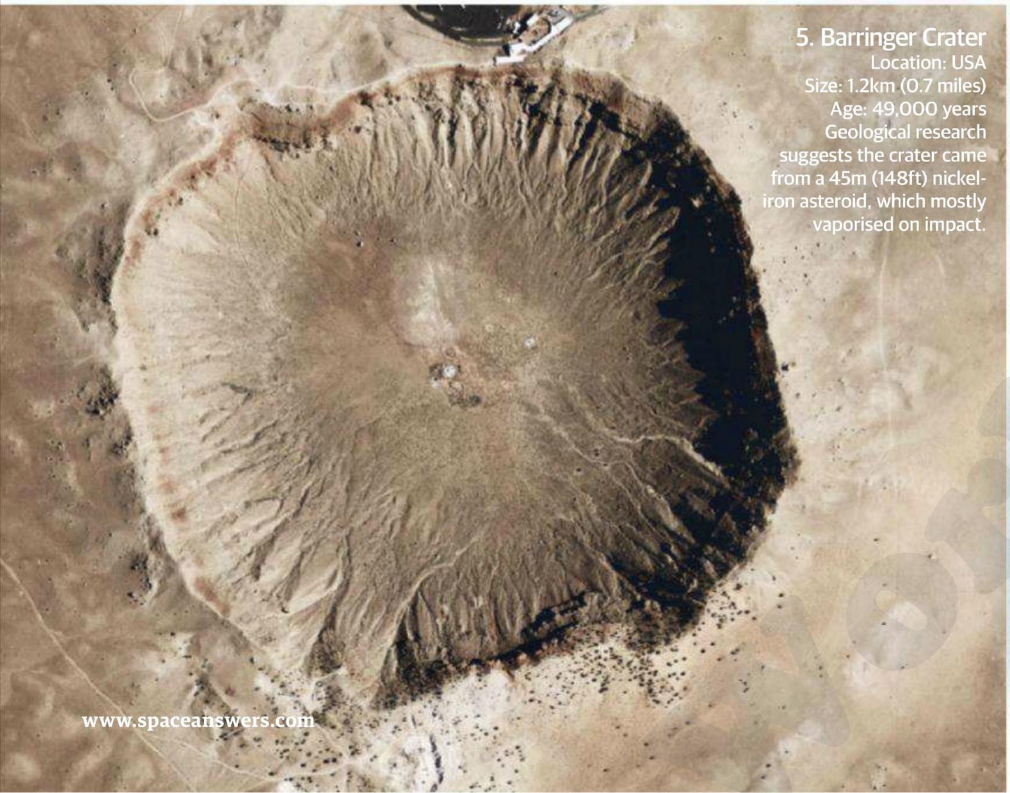
Location: Canada
Size: 3.4km (2.1 miles)
Age: 1.4 million years
As a lake with no connection to other bodies of water, Pingualuit Crater has preserved sediments from before the Pleistocene ice age, capturing a wealth of geological history.



3. Chicxulub

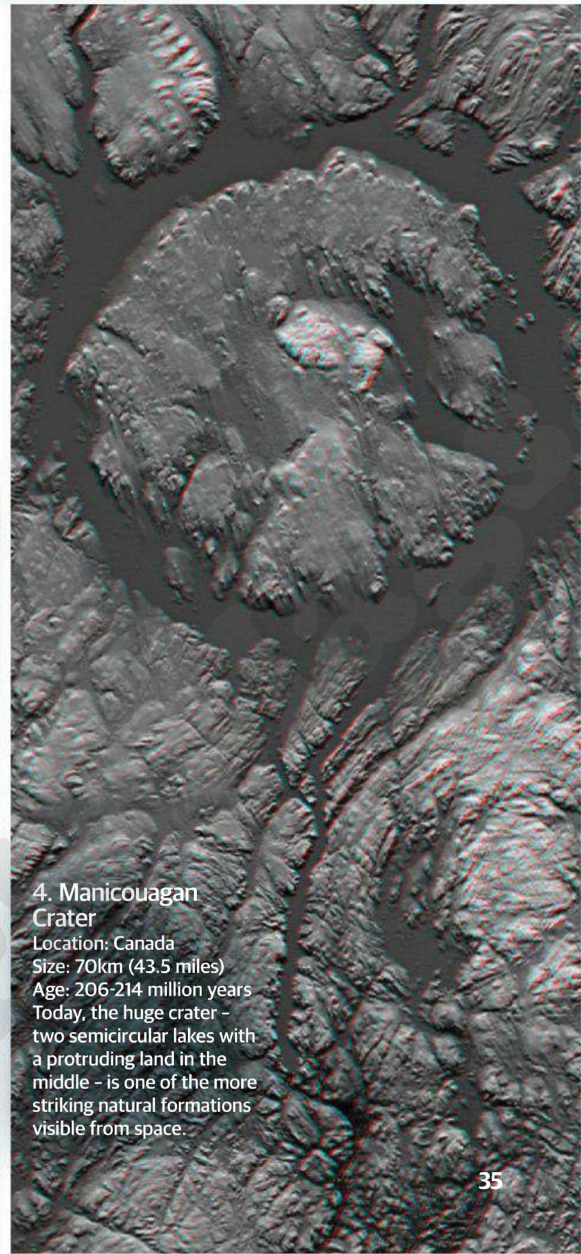
Location: Mexico
Size: 200km (124 miles)
Age: 65 million years
Scientists believe this massive crater in the Yucatan Peninsula is probably from the comet or asteroid impact that killed the dinosaurs.





5. Barringer Crater

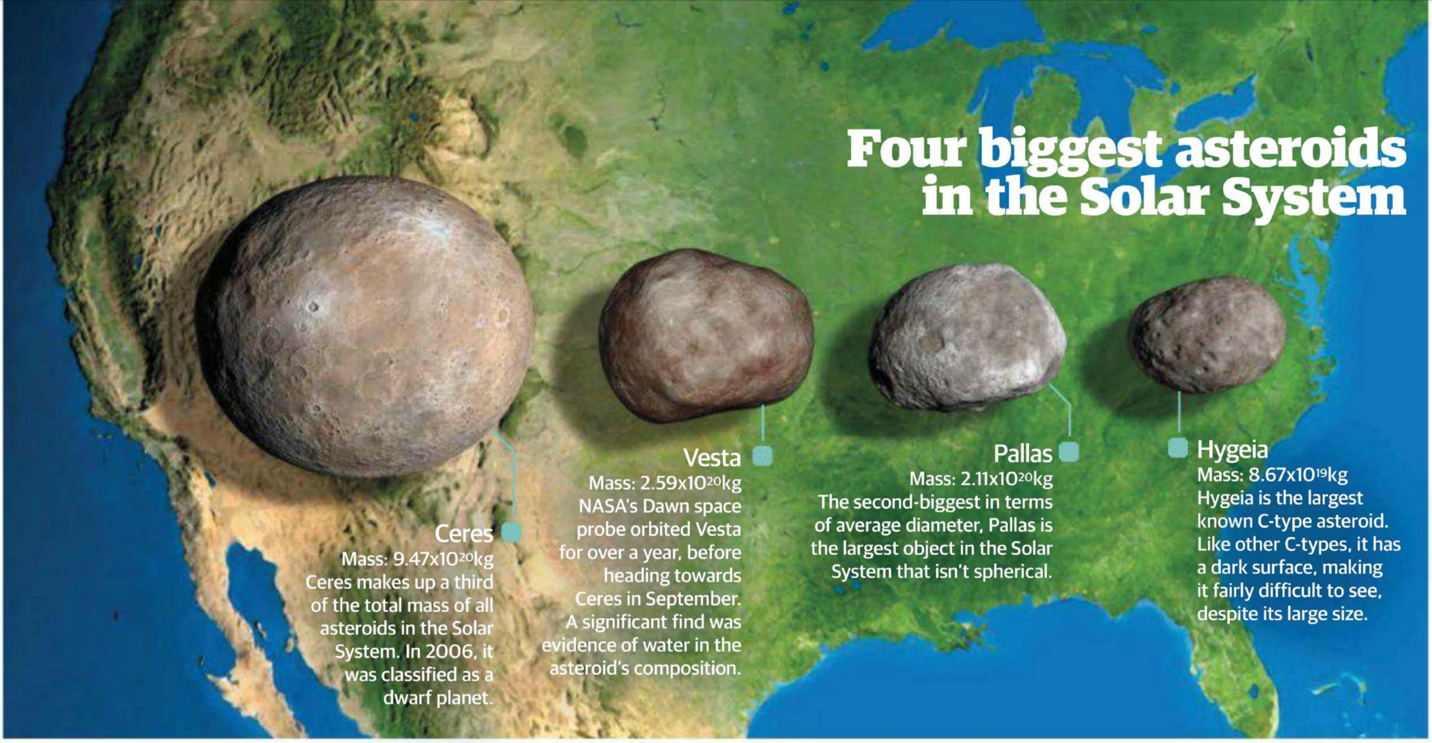
Location: USA
Size: 1.2km (0.7 miles)
Age: 49,000 years
Geological research suggests the crater came from a 45m (148ft) nickel-iron asteroid, which mostly vaporised on impact.



4. Manicouagan Crater

Location: Canada
Size: 70km (43.5 miles)
Age: 206-214 million years
Today, the huge crater – two semicircular lakes with a protruding land in the middle – is one of the more striking natural formations visible from space.

Four biggest asteroids in the Solar System



Ceres
Mass: 9.47x10^{20}kg
Ceres makes up a third of the total mass of all asteroids in the Solar System. In 2006, it was classified as a dwarf planet.

Vesta
Mass: 2.59x10^{20}kg
NASA's Dawn space probe orbited Vesta for over a year, before heading towards Ceres in September. A significant find was evidence of water in the asteroid's composition.

Pallas
Mass: 2.11x10^{20}kg
The second-biggest in terms of average diameter, Pallas is the largest object in the Solar System that isn't spherical.

Hygeia
Mass: 8.67x10^{19}kg
Hygeia is the largest known C-type asteroid. Like other C-types, it has a dark surface, making it fairly difficult to see, despite its large size.

in Chile that will deliver unprecedented detail when it comes online around 2020. "It's an 8.4-metre (27.5-foot) aperture, and it's extremely wide-field. So although it's not being built expressly for near-Earth objects, they simply can't avoid them."

> "We had an object about the size of a small or fairly good-sized automobile that actually hit in October 2008. It was discovered about 24 hours in advance"

In the effort to catalogue potential hazards, discovering a new comet or asteroid is only the beginning. To assess the possibility of Earth impact, astronomers need to figure out where each is going, which means pinpointing its position and trajectory.

Yeomans says stars provide the starting point: "Say you've got four stars in the background and you've got an asteroid in the foreground. You can measure the distance between asteroid and star 1, the distance between asteroid and star 2, the distance between asteroid and star 3 and so on. Since you know the positions of the stars you can determine the position of the asteroid when you took that image. If you have a bunch of these observations, then you know where the asteroid was - its angular position in the sky."

The key to improving accuracy, he explains, is multiple observations: "As the asteroid is observed more and more, day after day, we get more of these observations, and so the orbit gets better and better. What we do is we start with a preliminary orbit and then we project that orbit forward in time through all of the observations we have in hand, and we ask the question, 'Well, how well did that preliminary orbit match where that asteroid was observed to have been?' Then we say, 'Oh well, it wasn't a perfect fit, but we can use the differences between the observed and the predicted position of the asteroid to refine the orbit and the next time we observe it we'll know better where it is.' We can predict its motion much better in the future as we get more and more observations on which to base the orbit."

The necessary follow-up observations have a surprising source. "The majority I would say are done by amateurs, actually," Yeomans says. "They're really amateurs in name only because they're extremely sophisticated observers, most of them."

Yeomans says the hub is the Minor Planet Center in Cambridge, Massachusetts, which acts as clearing house for all data on the Solar System: "The amateurs, or the professionals for that matter, will take their data, report the time at which they observed, and the so-called right ascension and declination, which are two measurements of where that asteroid was at that given time. They will send those observations to the Minor Planet Center, and the Minor Planet Center will do a preliminary orbit and ask the observer community to follow up. Then amateurs take a look at the Minor Planet Center's follow-up list and say, 'All right, if this object has been just discovered, it needs additional observations so that the orbits can be computed more accurately.'"

With sufficient observations in hand, it's time to crunch the numbers. Yeomans says the Minor Planet Center sends preliminary orbit data to the Jet Propulsion Laboratory in Pasadena, California, as well as a team in Pisa, Italy: "As more and more data comes in, we in our office here and our colleagues in Pisa also, run the orbits for these objects forward 100 years and see if there's any interesting close-Earth approaches. And if there are, we also do impact probability calculations."

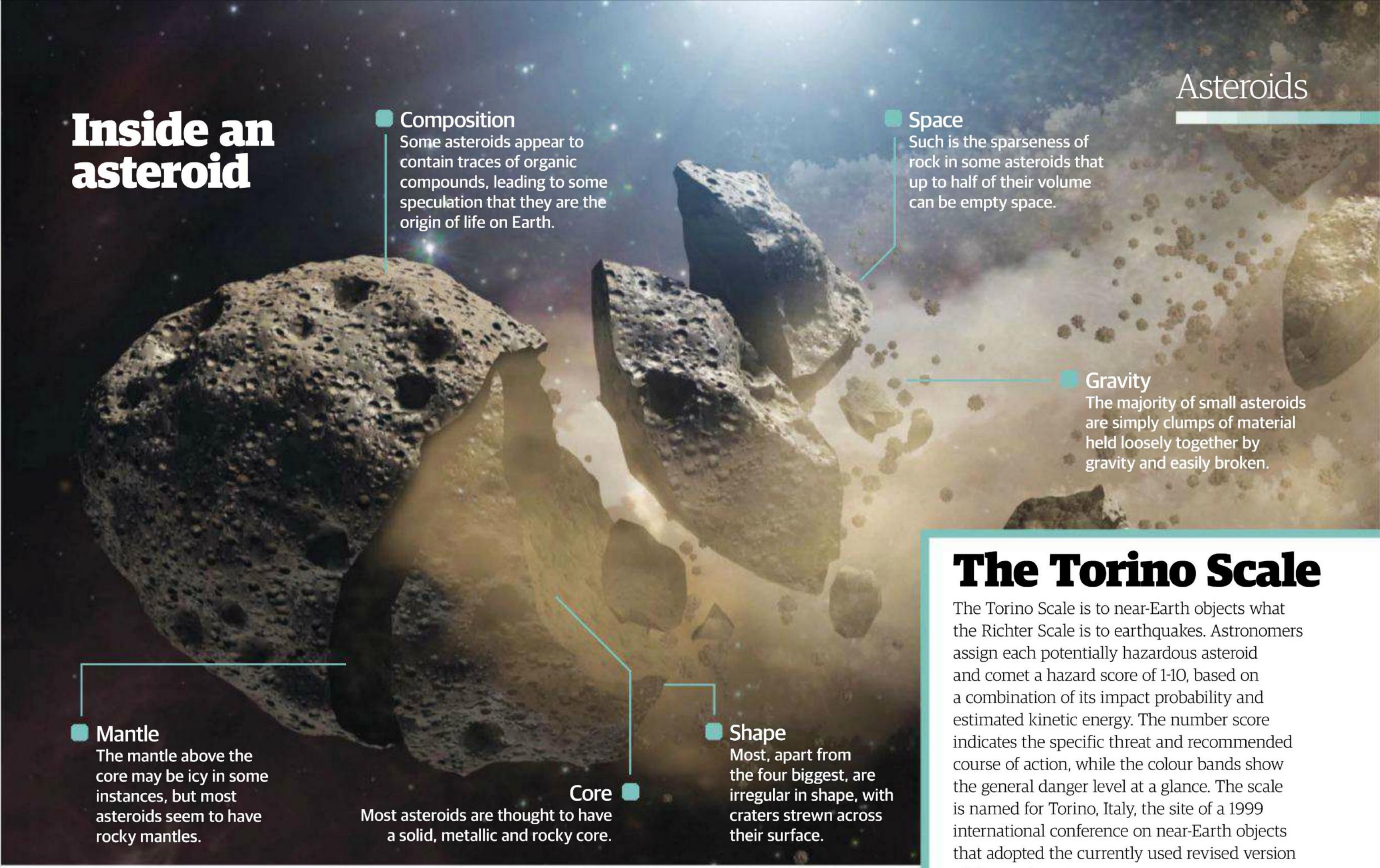
To understand the risk of impact, astronomers consider the uncertainty ellipsoid - the possible positions and orbits of the object - and then perform a Monte Carlo analysis to assess the chance of a hit.

"The Monte Carlo analysis takes every orbit in that uncertainty ellipsoid, even the ones at the edges, runs them forward 100 years, and asks will that orbit run into the Earth," Yeomans says. "Then you take another one inside the uncertainty ellipsoid at the current time and run it forward 100 years and ask will that orbit hit the Earth at any time. If a hundred out of a thousand hit, you have a ten per cent impact probability."

To date, Yeomans says, the analysis hasn't shown any objects with a high likelihood of hitting us: "Dozens of them have non-zero impact probability, but most of them are extremely small. They're 10^{-5}, 10^{-6}. There are none that reach one per cent. There are some that reach 1 in 500 or 1 in 300. That's about as high as we get at the moment."

The NEO Program hopes to locate at least 90 per cent of the asteroids and comets that approach Earth

Inside an asteroid



Composition
Some asteroids appear to contain traces of organic compounds, leading to some speculation that they are the origin of life on Earth.

Space
Such is the sparseness of rock in some asteroids that up to half of their volume can be empty space.

Gravity
The majority of small asteroids are simply clumps of material held loosely together by gravity and easily broken.

Mantle
The mantle above the core may be icy in some instances, but most asteroids seem to have rocky mantles.

Core
Most asteroids are thought to have a solid, metallic and rocky core.

Shape
Most, apart from the four biggest, are irregular in shape, with craters strewn across their surface.

Yeomans says NASA's first priority has been to find the asteroids that are big enough to cause worldwide problems if they struck Earth: "Their initial goal was to find at least 90 per cent of the near-Earth asteroids that were larger than a kilometre (0.6 miles). There's about a thousand of those, and we've discovered already about 94 per cent, about 940 of them. And none of them represent a threat in the next century."

While the search for the missing six per cent goes on, the hunters have broadened their scope. "Now NASA's goal is to find 90 per cent of the objects 140 metres (459 feet) and larger, because those are the objects that cause regional damage or tsunamis should they hit," Yeomans says. "About 40 per cent of those have been found, and none of those represent a significant threat in the next hundred years."

For smaller asteroids, Yeomans reports more modest progress: "When you get down to around 30 metres [98 feet], we've found less than one per cent of the total population, because there's so many of them. For those guys, it might make sense to have a telescopic survey engineered to find them on their last approach, because you're not going to discover them until they get very close or they're about to hit."

Yeomans says, in these cases, an early warning system makes more sense than deflecting the threat. "If it's only a 30-metre [98-foot] object, it would be sufficient to find it a few days in advance of an impact because you know the line along which it will strike, and if that line went through any populated areas you could evacuate. More than likely it would hit over the ocean and not be a problem. We could do the calculation and say, 'All right, if it's going to hit the Earth, it's going to hit along this line, which could run from South America out to the Pacific Ocean to China, say.' And if any of that line goes near a population centre, we could say, 'All right, you folks would be wise to move a couple of hundred kilometres from that line.' You don't have to go and stop each one; you just have to know it's coming."

If we detect a larger threat – the sort that could devastate a wide area or wipe out humanity – we'll need to alter its path. Contrary to Hollywood predictions, blowing it up wouldn't be a good option, as it would only create more chunks to contend with.

Yeomans describes the more practical reality: "The easiest technique would simply be to run into it with a spacecraft and slow it down or speed it up so that in 20-30 years, when it was predicted to hit the Earth, it wouldn't. We would alter its trajectory just a bit, a millimetre or two a second."

NASA took this plan through a successful dry run in 2005 with its Deep Impact probe. "We purposely ran into a comet, Tempel 1," Yeomans says. "But the technology that was employed would be the same that would be used to hit an asteroid. So, we've demonstrated that it can be done. All you have to do is find it early enough that will give you enough time to get your spacecraft up there and run into it several years in advance of the projected impact because you need time for the change in velocity to build into a change in the position at the time."

Another possibility is to attach solar sails that would use the Sun's energy to nudge the object into a different orbit. Some have even proposed detonating a nuclear bomb far enough away that it doesn't break the asteroid apart, but irradiates the surface, making the asteroid recoil enough to shift its trajectory.

The elaborate schemes are conjecture at this point. "For my money, the simplest and easiest technique is the best," Yeomans says. "And simply running into it, if you have the time, is the way to go." ■

The Torino Scale

The Torino Scale is to near-Earth objects what the Richter Scale is to earthquakes. Astronomers assign each potentially hazardous asteroid and comet a hazard score of 1-10, based on a combination of its impact probability and estimated kinetic energy. The number score indicates the specific threat and recommended course of action, while the colour bands show the general danger level at a glance. The scale is named for Torino, Italy, the site of a 1999 international conference on near-Earth objects that adopted the currently used revised version of the scoring system.

No hazard	0	At this level the likelihood of an asteroid or comet striking Earth is effectively zero.
Normal	1	A near pass is predicted, but it poses no unusual level of danger and a hit is extremely unlikely.
Meriting attention by astronomers	2	Makes a near pass and may merit attention, but inspection will likely reduce threat.
	3	A collision has a 1 per cent or greater chance, capable of localised destruction.
	4	The threat of a collision remains one per cent, but observations will probably deem it no threat.
Threatening	5	A close encounter that could cause regional devastation. Critical attention needed.
	6	Poses a serious but uncertain threat of global catastrophe, requiring contingency planning.
	7	A close encounter that would require immediate planning if it is within a century.
Certain collisions	8	A collision with Earth is certain. Localised destruction or a tsunami will result.
	9	Unprecedented devastation, including major tsunami. Occurs every 100,000 years.
	10	May threaten the future of civilisation. Occur less than once per 100,000 years.

5 amazing facts about

Weather on other planets

Pluto freezes over every century

Pluto's highly elliptical orbit around the Sun takes about 248 years and, when it reaches its furthest point, its gases freeze and the atmosphere collapses. As it moves back towards the Sun, the temperature rises and the ice turns back to gas.

Rain falls on Titan once every 1,000 years

Titan's climate cycle is quite similar to Earth's, except it involves liquid methane instead of water. There are many centuries between Titan's rainstorms on average but, when they occur, they can dump metres' worth of methane rain.

Neptune's winds are twice the speed of sound on Earth

You might think Earth is breezy, but spare a thought for Neptune. It has the most powerful winds in the Solar System, reaching up to 2,500km/h (1,600mph) in some instances.

The temperature on Mars can swing by 150 degrees in a day

Daytime on Mars can be a rather comfortable 25°C (80°F) as the Sun makes its way through the thin atmosphere, but at night the lack of sunlight coupled with the minimal atmosphere can see the temperature drop to almost -130°C (-200°F).

Auroras generate one trillion watts of power

Auroras, the interaction of charged particles with the Sun in the upper atmosphere, can generate the equivalent power to a sixteenth of that used by humans around the world.

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An artist's impression of a Gamma Ray Burst

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Background Image: A Liverpool Telescope image of Comet C2002T7

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The search for space ice

Discover where ice can be found in our Solar System and what scientists can learn from studying it

On Earth, pretty much the only time we think about ice is when we slip over on it, or when we drop a couple of cubes into a refreshing beverage on a hot summer's afternoon.

But while it's very common here on Earth, finding ice in the Solar System is a bit more of an adventure. It's not exactly abundant… but it's not rare to find, either. It's a matter of knowing where to look. Whether it's lurking at the bottom of a crater or plainly visible at a planet's polar regions, ice has been spotted by spacecraft all over the Solar System.

Like a bad poker player, ice has several 'tells' that inform scientists of its presence. Satellites swooping over a suspected icy area are on the hunt for patches of unusual brightness, or 'spectrums' of elements that include hydrogen or oxygen – of course, the core elements of water.

Sometimes ice shows up in more unusual ways. The Lunar Reconnaissance Orbiter (LRO) is a NASA spacecraft currently orbiting the Moon. It has a laser altimeter on board, which shoots beams of light at the surface and maps what comes back. Through this method, the LRO scoped out the bottom of the south pole's Shackleton Crater and found what is believed to be water ice.

The LRO also has a radar instrument on board, which scanned the sides of the crater during another orbit of the Moon. Various types of terrain show up differently on radar; for example, a flat surface appears black because all of the radar pulses hit at the same height. The 'signature' that came back to the LRO showed possible ice in the walls of the crater.

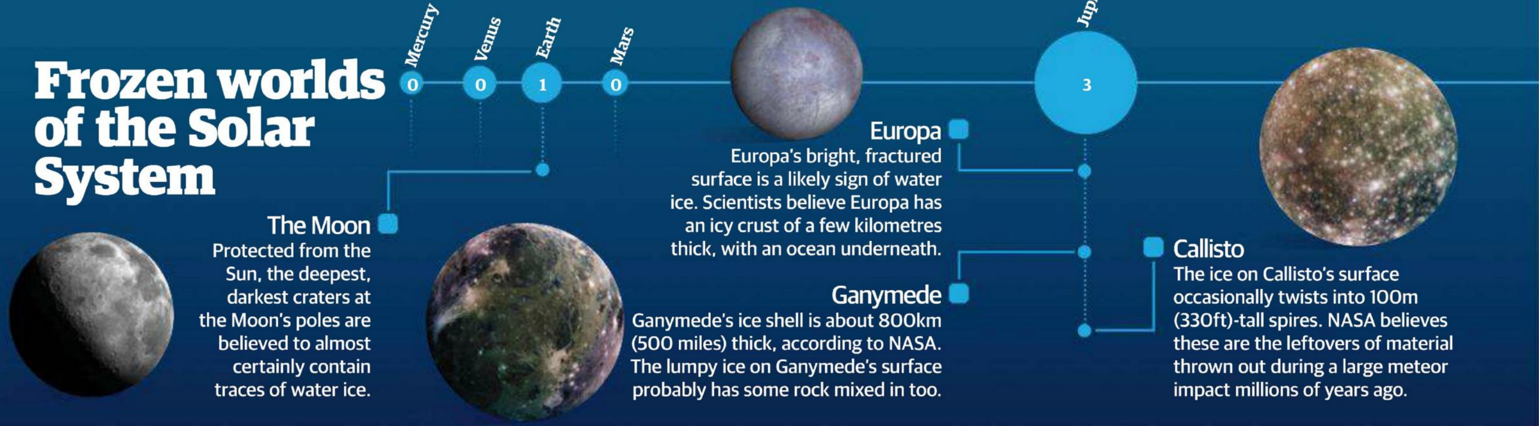
On Earth, we tend to think of ice as water ice. But when it gets cold enough, anything will freeze. Picture putting an ice cube from Titan in your drink. At first glance, the ice wouldn't be all that different, because the Saturnian moon is believed to have water ice at the surface.

But you don't want to drink the ice: it's likely laced with ammonia – which on Earth is an industrial poison. It also contains methane, which in gas form contributes to the greenhouse effect on Earth. Titan's a bit of a weird moon. It sits about 1.4 billion kilometres (870 million miles) from the Sun – around ten times farther away than Earth. The Sun is but a bright star in the sky, providing wimpy heat. But Titan also gets warmth from its huge host planet Saturn, which it circles every 16 days.

NASA's Cassini spacecraft has been moving around Saturn and its many moons ever since 2004, and occasionally it will take a pass by Titan. Scientists working on the Cassini mission have been wondering how Titan maintains methane in its atmosphere. It should have leaked out a long time ago – unless there was some kind of an internal source that regenerates the methane.

Most of Titan is covered with water ice, but scientists suspect there's a big watery ocean underneath. In 2010, Cassini scientists released a study proposing that ocean might have ammonia 'salting' the liquid. The water-ammonia slush, if it rubbed

Frozen worlds of the Solar System

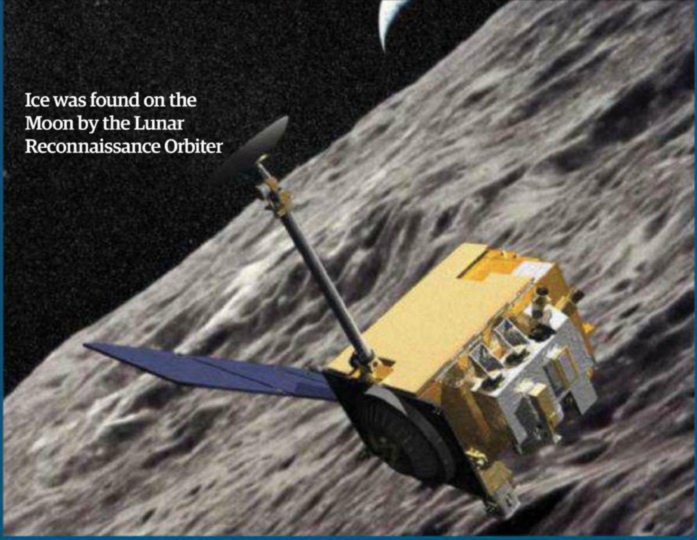


The Moon
Protected from the Sun, the deepest, darkest craters at the Moon's poles are believed to almost certainly contain traces of water ice.

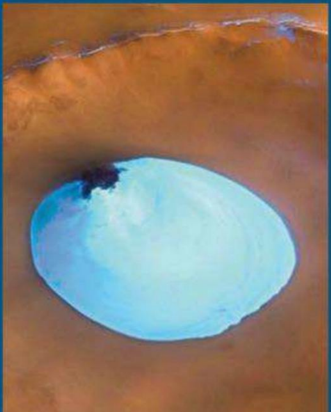
Europa
Europa's bright, fractured surface is a likely sign of water ice. Scientists believe Europa has an icy crust of a few kilometres thick, with an ocean underneath.

Ganymede
Ganymede's ice shell is about 800km (500 miles) thick, according to NASA. The lumpy ice on Ganymede's surface probably has some rock mixed in too.

Callisto
The ice on Callisto's surface occasionally twists into 100m (330ft)-tall spires. NASA believes these are the leftovers of material thrown out during a large meteor impact millions of years ago.



Ice was found on the Moon by the Lunar Reconnaissance Orbiter



The Mars Express Orbiter took this picture of water ice in a Martian crater close to the north pole

> "NASA believes there could be ice lurking in the deepest craters on the Moon"

against the ice long enough, would release methane from the ice… which then heads up into the atmosphere, the scientists suggested.

If you sold the Solar System as a series of tourist destinations, Titan would be a popular spot for ice skating. But say you're a Solar System voyager looking for a place far from the madding crowd. Thankfully, there are other spots you can land on.

Perhaps watching frozen ice come alive on a comet is more your style. As the comet gets closer to the Sun, the heat of the star warms the surface. Eventually, bits of ice and gas blast off and form those beautiful tails that stretch for thousands of miles. If the comet is close enough and large enough, you can see the tails from Earth. NASA smashed a spacecraft into Comet Tempel 1 in 2005. The appropriately named Deep Impact uncovered a few interesting things.

Just beneath the surface of the comet is both water ice and 'dry' (carbon dioxide) ice. When the comet gets close to the Sun, the dry ice melts first. But if it's buried underneath more water ice – as is the case on Tempel – it's able to stay intact for a longer period of time.

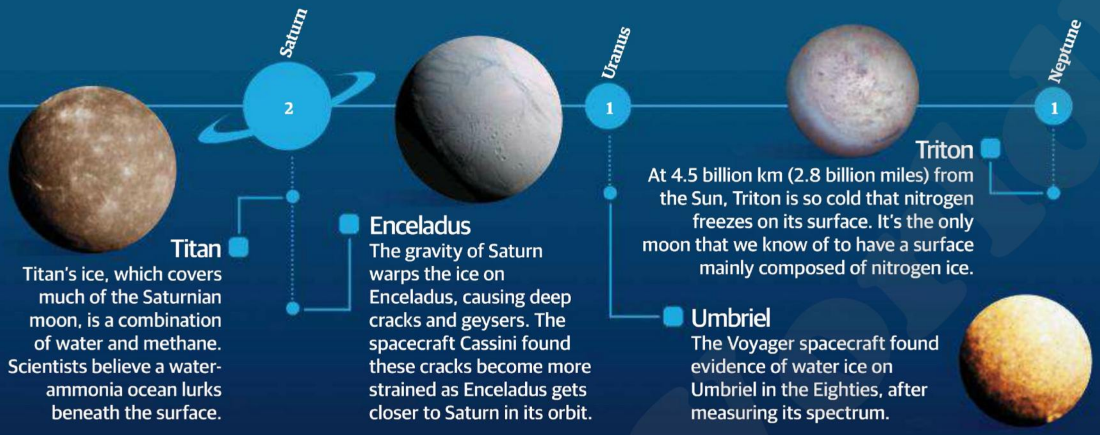
Scientists believe comets are formed in the 'suburbs' of the Solar System, in a region known as the Oort Cloud. Over millions and millions of years, bits of dust and water ice and dry ice slowly gelled together, forming the spectacular comets we can see today. This means if we study comets closely enough, we may very well get a clue as to how the early Solar System once looked.

There's no need to head to the outer Solar System to find ice, though. In fact, there's extraterrestrial frozen material a few days' journey away from Earth with current technology. That destination, of course, is the Moon. We used to think the surface was entirely made up of regolith, or Moon dirt. But some were curious about the deepest craters on our satellite. Could ice lurk there, protected from the rays of the Sun? NASA seems to think the answer is yes, after examining data from several spacecraft. In 2009, the agency threw the ageing Lunar Crater Observation and Sensing Satellite (LCROSS) at the floor of the Cabeus Crater, near the Moon's south pole. The suicide mission did have a scientific purpose: to measure the plumes of matter that LCROSS dug up when it hit the ground. NASA detected hydroxyl, a key indicator of water ice.

Since then, NASA has uncovered more evidence of ice on the Moon. For example, a radar instrument aboard the Chandrayaan-1 spacecraft found ice deposits at the north pole. As previously mentioned, NASA's Lunar Reconnaissance Orbiter found probable ice lining the walls of the Shackleton Crater, and possible ice on the bottom (appropriately enough, the crater is named after Antarctic explorer Ernest Shackleton).

If there is ice there, the Moon is an accessible spot to retrieve fragments of the early Solar System. It's also an ideal spot to set up a lunar base, as humans may not need to cart water with them to the Moon after all.

Our celestial icy tour does not stop there. There are many spots in the Solar System for fans of the frozen stuff. Check out the boxout below to see where else ice can be found.



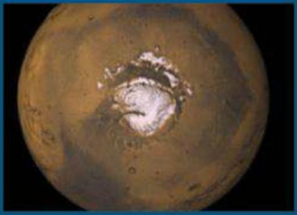
Titan
Titan's ice, which covers much of the Saturnian moon, is a combination of water and methane. Scientists believe a water-ammonia ocean lurks beneath the surface.

Enceladus
The gravity of Saturn warps the ice on Enceladus, causing deep cracks and geysers. The spacecraft Cassini found these cracks become more strained as Enceladus gets closer to Saturn in its orbit.

Triton
At 4.5 billion km (2.8 billion miles) from the Sun, Triton is so cold that nitrogen freezes on its surface. It's the only moon that we know of to have a surface mainly composed of nitrogen ice.

Umbriel
The Voyager spacecraft found evidence of water ice on Umbriel in the Eighties, after measuring its spectrum.

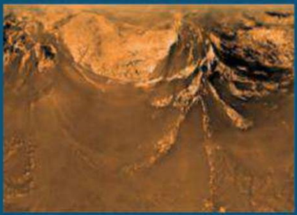
Types of ice in the Solar System



Dry ice

Found on: Mars

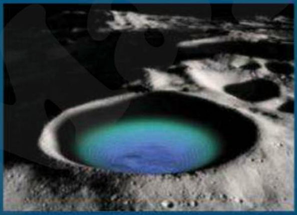
The Red Planet has carbon dioxide (or 'dry') ice at its poles. The caps are combinations of water and dry ice that shrink in the summer. In September, NASA announced the Mars Reconnaissance Orbiter had even found carbon dioxide snow clouds drifting over the south pole. Skiing holiday, anyone?



Methane ice

Found on: Titan

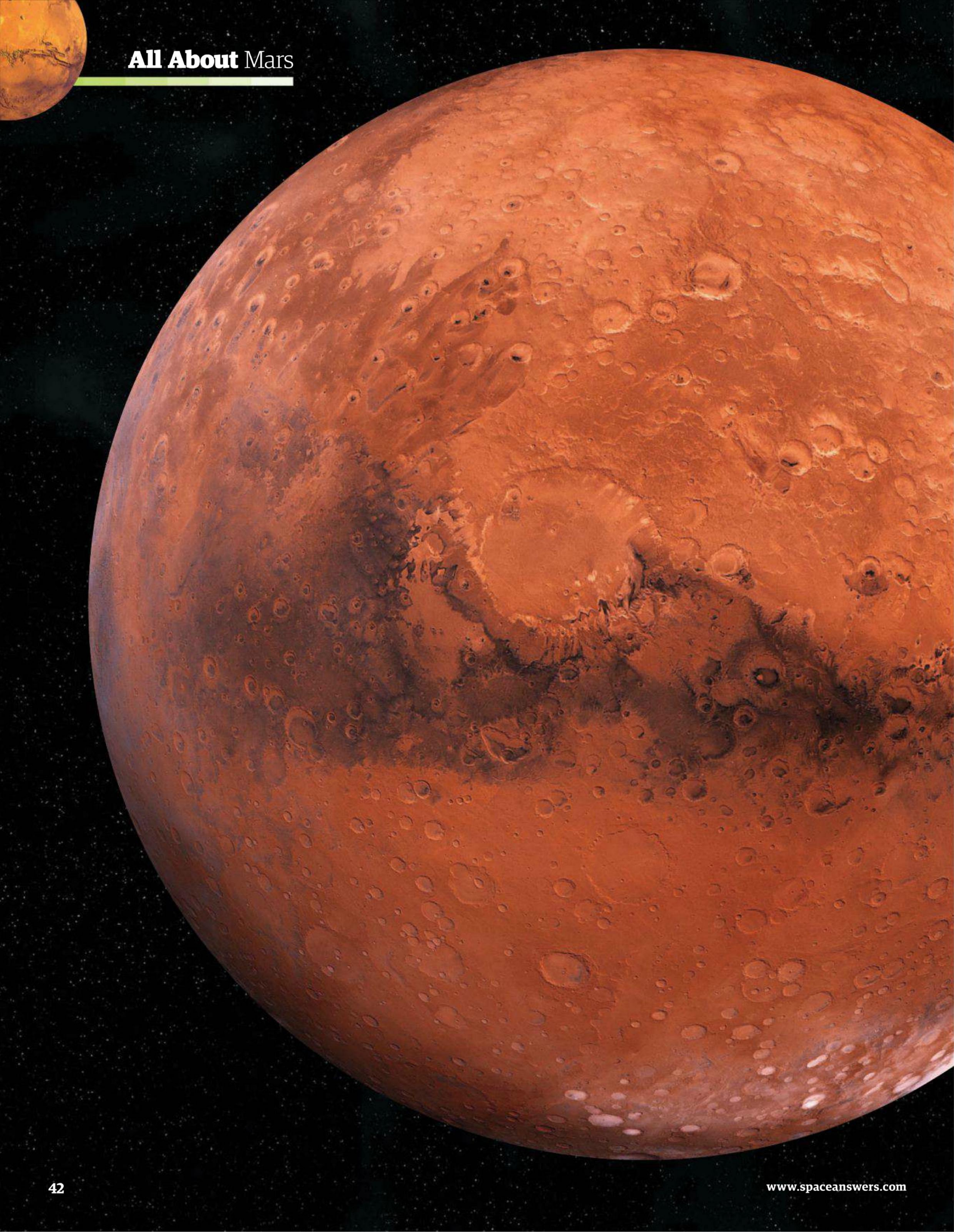
While most of Titan is covered in water ice, scientists think there's methane ice too. Titan is shrouded by a thick methane atmosphere that should have dissipated ages ago. NASA believes that frozen methane dissipates into the atmosphere as a water-ammonia ocean rubs against the ice.



Water ice

Found on: The Moon

It's believed that there is abundant water ice at the north and south poles of the Moon, buried in the deepest craters and sheltered from sunlight. One prominent example are the walls and base of the Shackleton Crater. It's thought the ice came from comets crashing into the lunar surface during the Solar System's formation.



All About... MARS

Written by Shanna Freeman

The fourth planet from the Sun and the seventh largest, the red and varied landscape of this once Earth-like planet has fascinated humanity since we first viewed it in the night sky. **All About Space** explores just why this planet holds such allure

Because it appears red due to the rust in its atmosphere, Mars has long been called The Red Planet. Its 'bloody' appearance is also why it was named after the Roman god of war. But that potentially scary appearance hasn't kept us from wanting to learn more about it. Mars formed about 4.6 billion years ago, along with the other planets in the Solar System. After the initial formation, Mars was bombarded at length by meteors, which caused its heavily cratered appearance. As the planet separated into layers, molten rock in the mantle pushed through the crust, resulting in volcanic activity. The activity released a lot of heat from the core, which led it to cool down very quickly. Atmospheric water likely froze, causing flooding, but the lack of atmospheric pressure meant that water was swirled away by solar winds. Eventually Mars settled down into the dry, dusty planet we've been watching since ancient times.

We can easily see Mars from Earth without a telescope, and it's actually easier to see when it's further away from the Earth in its orbit because our atmosphere gets in the way. We've sent lots of probes to the planet, including the recent addition of NASA's Curiosity rover. So far we've discovered that Mars is so much like the Earth, but also so very different. It is a terrestrial planet and has almost identical geographical features and a similar axial tilt (which results in seasons). It also has basically no atmosphere, no liquid water and wildly fluctuating temperatures on the surface. If there are any Martians lurking around, they have to be a hardy group – and so far they've eluded detection. Mars is red, but not all red. Although we can see the planet, we can't actually see any of its features. We do, however, see albedo features, areas of light and dark. While most of the planet is red there are also bright white areas at the poles, some upland areas, and also in the form of ice clouds. The darker spots are places where the intense wind has removed the dust to expose basaltic volcanic rock.

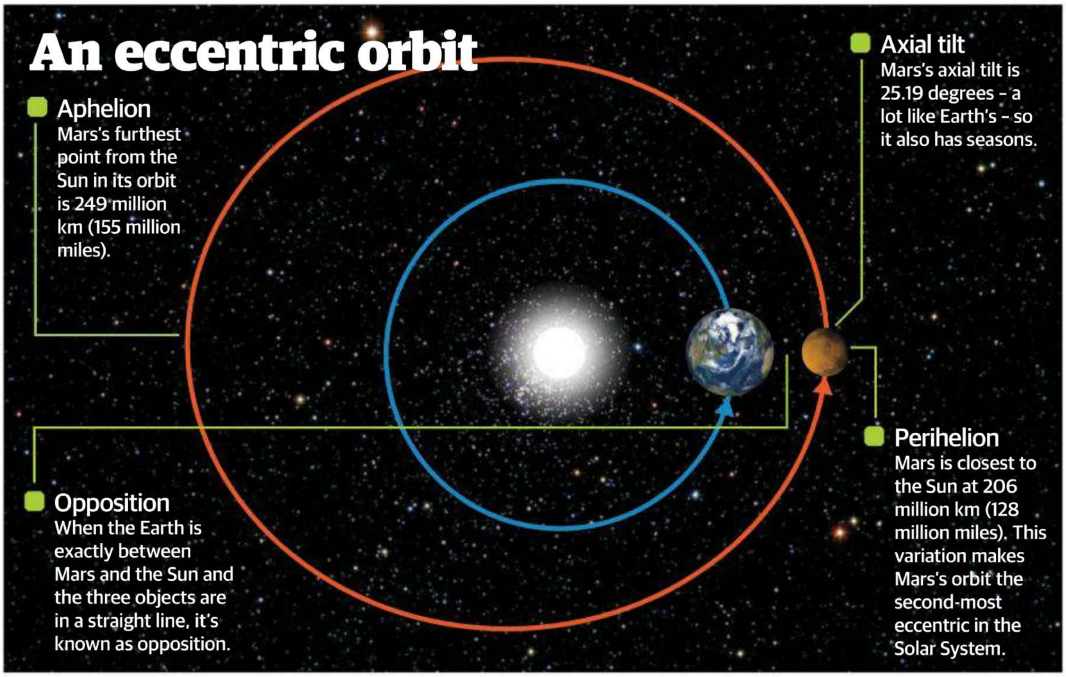
Mars is the fourth planet from the Sun in the Solar System, right between the Earth and Jupiter. Size-wise it is the second-smallest planet behind Mercury. Despite all of the Earth comparisons, it's about half the diameter of Earth, and much less dense. In fact, its mass is about 11 per cent that of Earth's and its volume is about 15 per cent. But because there are no oceans on Mars, it has the same amount of dry land as the Earth does.

The planet's average distance from the Sun is about 228 million kilometres (142 million miles). It takes 687 Earth days to orbit the Sun, but Mars has a very eccentric elliptical orbit. Its eccentricity is 0.09, which is the second-most eccentric in the Solar System behind Mercury (the Earth has an orbital eccentricity of 0.0167, which is almost a circle). But we believe that Mars once had a much rounder orbit – it has changed due to gravitational influences from the Sun and other planets. Rotation-wise, a Martian day is just a bit longer than an Earth day at 24 hours, 39 minutes and 35 seconds. Mars is also tilted 25.19 degrees, close to the Earth's axial tilt of 23.44 degrees. That means depending on where the planet is in its orbit around the Sun, different hemispheres will be exposed to more light – better known as seasons. They aren't seasons like we know them, which are fairly equal in length on Earth. On Mars, spring is seven months long, for example, while winter is only four. The seasons are longer because the year is longer – Mars is further away from the Sun than the Earth – but they vary because of the eccentricity of Mars's orbit.

Mars also has two natural satellites, or moons – Phobos and Deimos. Both are potato-shaped and may have been asteroids that got trapped by Mars's gravitational pull or they could have formed from material ejected from Mars during impact. The planet might also have other tiny satellites that have yet to be discovered.

> "Because there are no oceans on Mars, it has the same amount of dry land as the Earth does"

An eccentric orbit



Aphelion
Mars's furthest point from the Sun in its orbit is 249 million km (155 million miles).

Axial tilt
Mars's axial tilt is 25.19 degrees – a lot like Earth's – so it also has seasons.

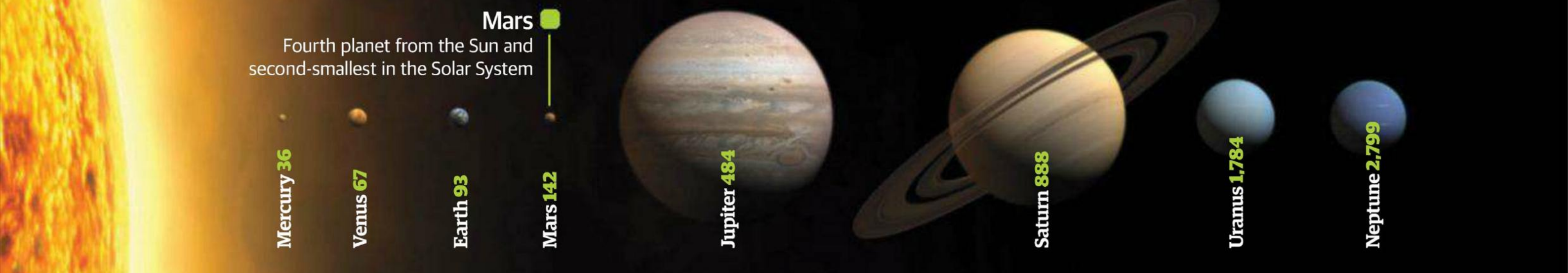
Opposition
When the Earth is exactly between Mars and the Sun and the three objects are in a straight line, it's known as opposition.

Perihelion
Mars is closest to the Sun at 206 million km (128 million miles). This variation makes Mars's orbit the second-most eccentric in the Solar System.

The planets in relation to the Sun

All figures = million miles from Sun

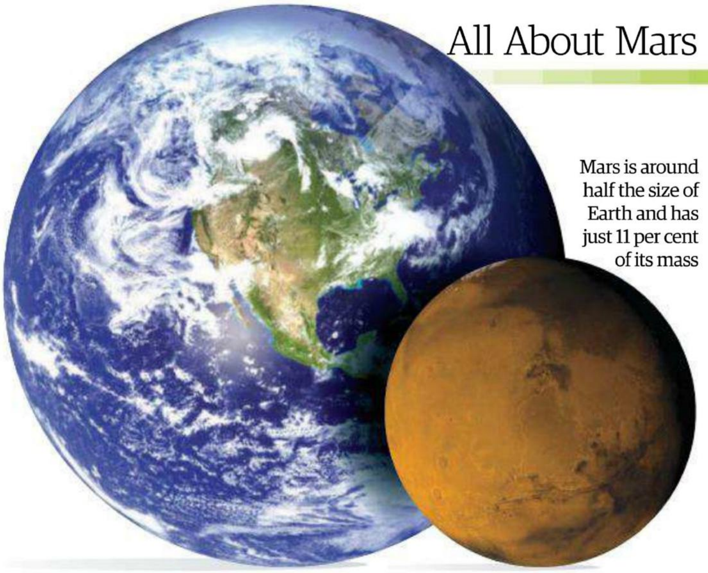
Mars lies 228 million km (142 million miles) from the Sun and 225 million km (140 million miles) from Earth



Mars
Fourth planet from the Sun and second-smallest in the Solar System

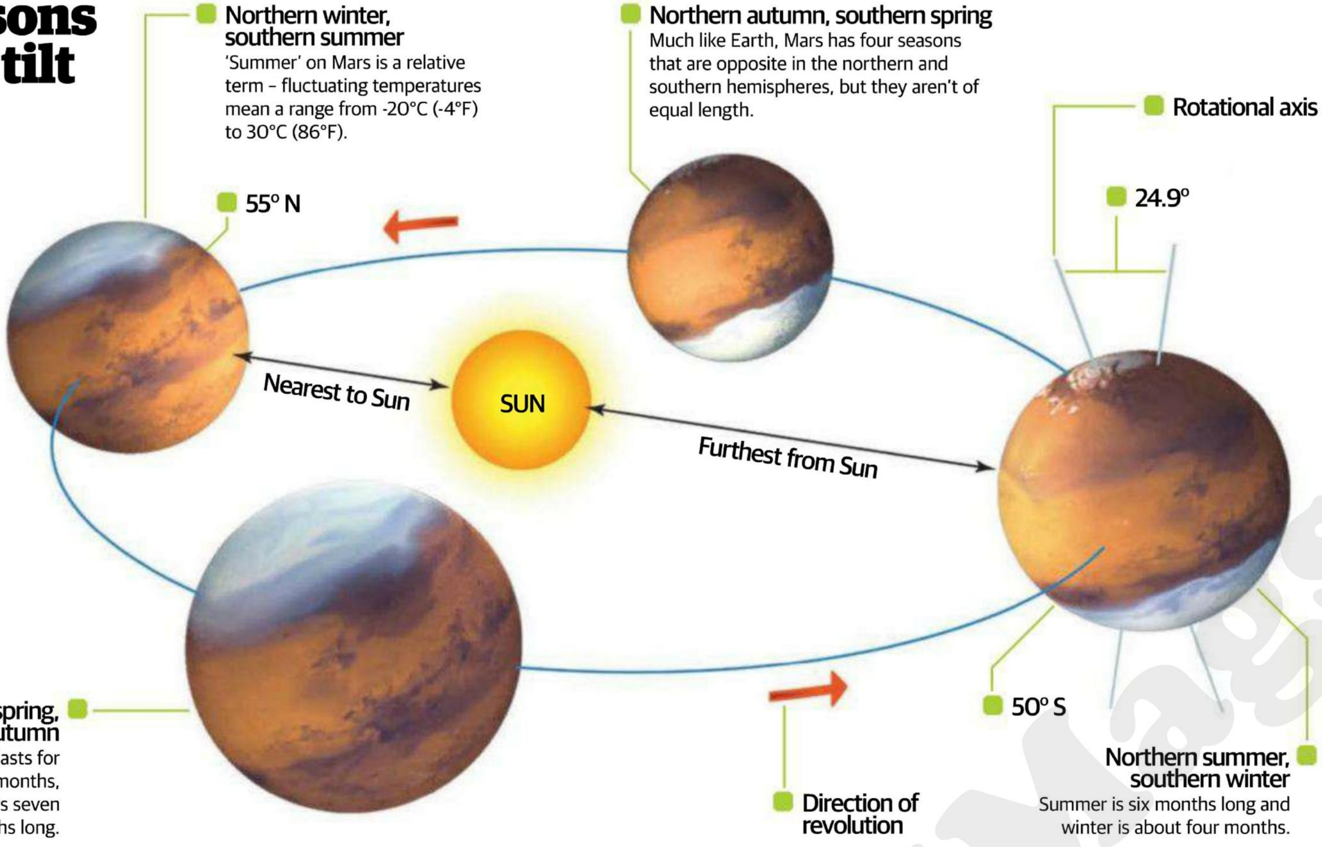
Over the years science fiction has often portrayed Mars as a sister planet to Earth and although there are many key differences – the small matter of life, for example – a true understanding can often be reached by making the right comparisons. NASA has referred to Earth as 'one of the best comparative laboratories' and the study of Mars can provide scientists with a control set for studying the potential for life beyond our world.

As mentioned, the chief of these differences is the size of the planet: Mars is a smaller world with 53 per cent the diameter and just 11 per cent the mass of Earth. The surface gravity on the Red Planet is 38 per cent that of Earth's, meaning that a human who can jump one metre (3.3 feet) on Earth could jump 2.6 metres (about nine feet) on Mars. As well as the similar land surface area the atmospheric chemistry is relatively similar especially when Earth and Mars are compared to other planets in the Solar System. Both planets have large polar ice caps made primarily of water ice, according to current thinking. Other similarities include a similar tilt in their rotational axis, which causes strong seasonal variability. ●



Mars is around half the size of Earth and has just 11 per cent of its mass

Seasons and tilt



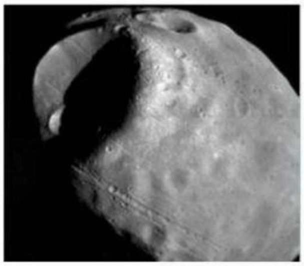
Northern winter, southern summer
'Summer' on Mars is a relative term – fluctuating temperatures mean a range from -20°C (-4°F) to 30°C (86°F).

Northern autumn, southern spring
Much like Earth, Mars has four seasons that are opposite in the northern and southern hemispheres, but they aren't of equal length.

Northern spring, southern autumn
Autumn lasts for about 5.3 months, while spring is seven months long.

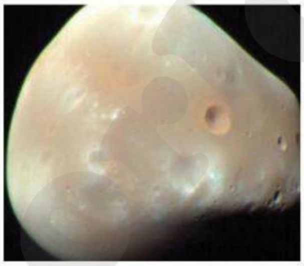
Northern summer, southern winter
Summer is six months long and winter is about four months.

The moons of Mars



Phobos

Phobos is the bigger of Mars's two satellites, and orbits the closest. In fact, it orbits closer to its planet than any other satellite in the Solar System. The distance from the moon to the planet is about 6,000km (3,700 miles) from the surface. Phobos has a radius of about 11km (seven miles) and is irregularly shaped and non-spherical. Its biggest feature is a large impact crater named Stickney, which has a diameter of about 9km (5.6 miles).



Deimos

Deimos is much farther from Mars than Phobos at around 23,400km (14,600 miles) away. It's also significantly smaller, with a radius of around 6km (four miles), and takes much longer to orbit Mars at 30.4 hours. Deimos, like Phobos, is not at all spherical. It has a very porous surface, and also features large craters relative to its size, with the two largest being Swift and Voltaire. Both craters are believed to be between 1 and 3km (0.6 and 1.9 miles) in diameter.

Mars inside and out

Its make-up may resemble Earth's, but Mars is a very different planet

Mars is a terrestrial, or rocky, planet – just like Earth. It also has a differentiated internal structure, meaning that there's an outer crust, a mantle and a core. However, that structure isn't exactly like the Earth's.

At the centre of the planet, Mars's core is believed to be between around 3,000 and 4,000 kilometres (1,850 and 2,500 miles) in diameter. It's mostly made up of iron, with nickel and traces of other elements, such as sulphur. Scientists believe that the core is mostly solid but may also contain a fluid layer. There is no magnetic field generated at the core, but Mars may have had a magnetic field in the past. There are currently areas of magnetisation at different places on the planet's surface. The differentiation process, in which heavier metals such as iron sunk through to the core while Mars was forming, may be responsible for the end of the Red Planet's magnetic field.

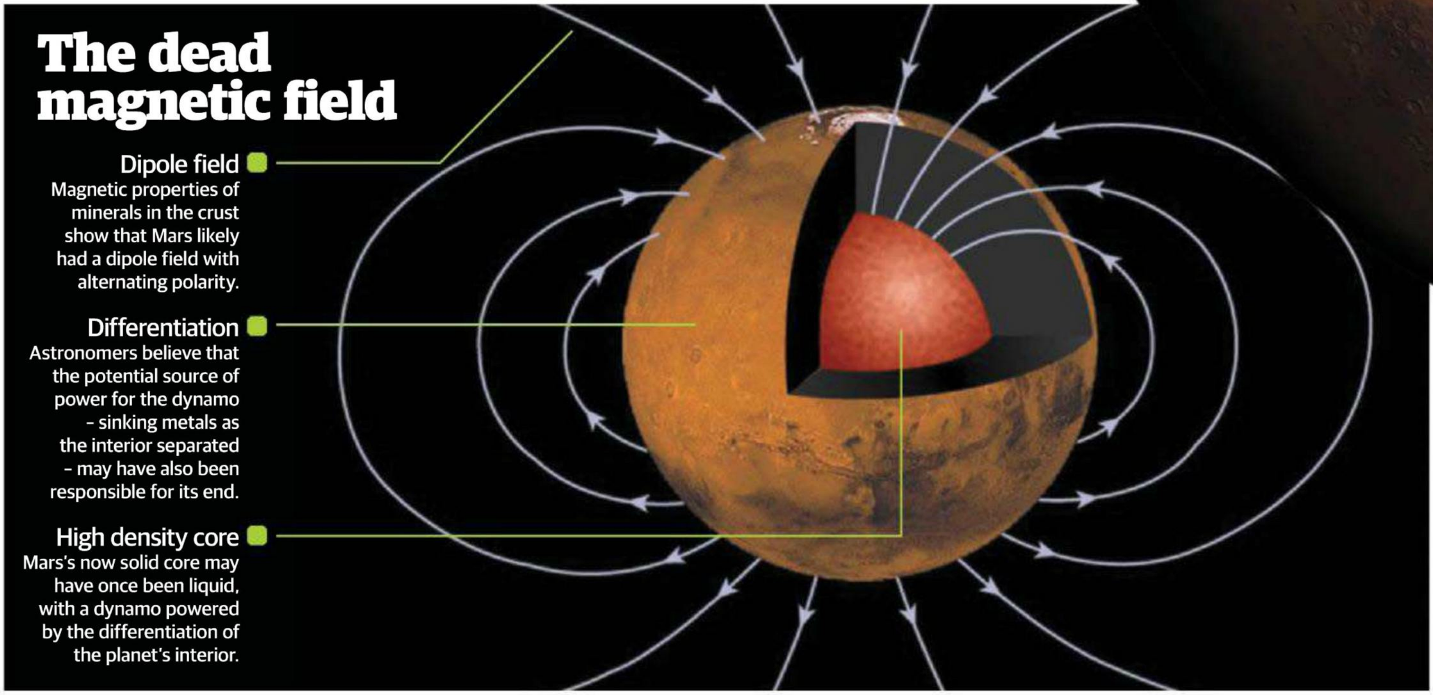
Atop the core lies Mars's silicate mantle, which is between 1,300 and 1,800 kilometres (800 and 1,100 miles) thick. Volcanic activity on the planet's surface originated here, resulting in the huge volcanoes, lava flows and other features that can be found on Mars's surface – however, the most recent volcanic activity likely took place about 2 million years ago. That may not be particularly recent by our standards, but it's fairly recent when it comes to Mars's history. These were lava flows, however; the volcanoes appear to be extinct.

Finally, there's the crust, which is about 25 to 80 kilometres (16 to 50 miles) thick. It contains oxygen, silicon, iron, calcium and other metals. The high concentrations of iron and oxygen result in rust – iron oxide – which is responsible in part for the red appearance of Mars. At its thickest the crust is more than twice as thick as the Earth's crust. The surface is covered with regolith in many places – a loose conglomerate of broken rocks, dirt and dust.

There isn't much atmosphere – the solar wind strips away molecules and carries them out into space. It is about 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon with trace gases as well.

> "The solar wind strips away molecules and carries them out into space"

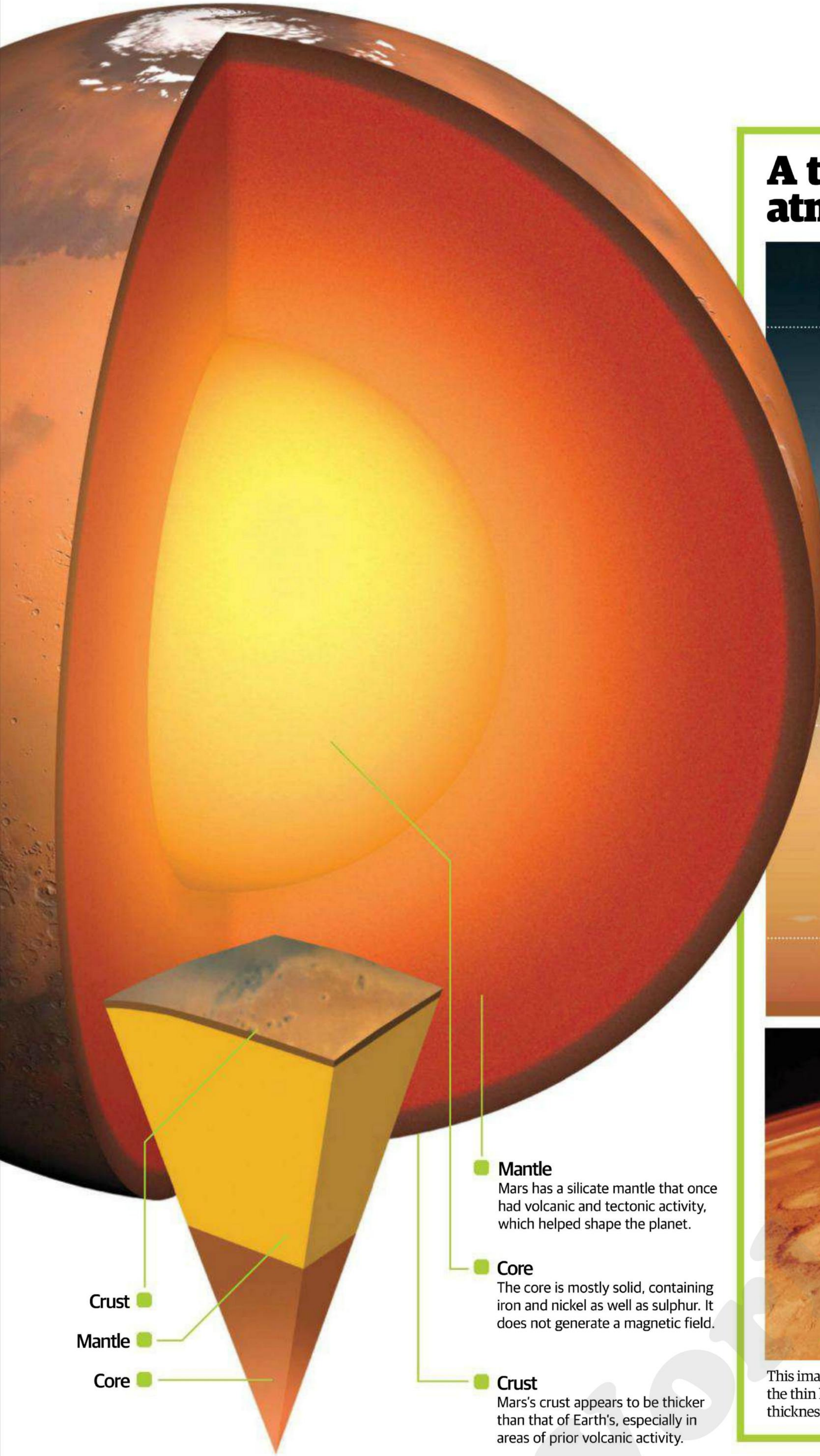
The dead magnetic field



Dipole field
Magnetic properties of minerals in the crust show that Mars likely had a dipole field with alternating polarity.

Differentiation
Astronomers believe that the potential source of power for the dynamo – sinking metals as the interior separated – may have also been responsible for its end.

High density core
Mars's now solid core may have once been liquid, with a dynamo powered by the differentiation of the planet's interior.

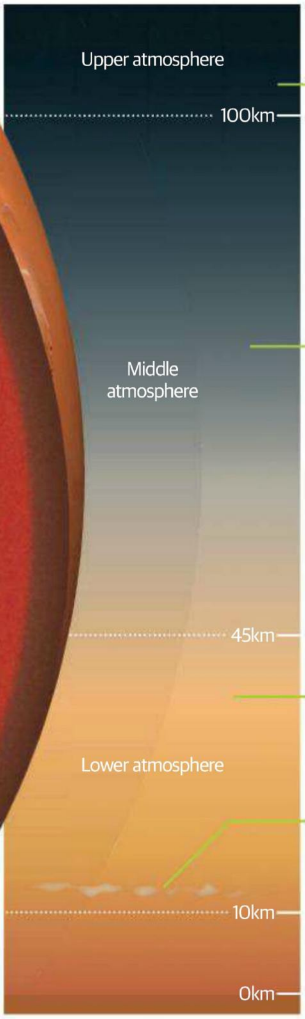


Mantle
Mars has a silicate mantle that once had volcanic and tectonic activity, which helped shape the planet.

Core
The core is mostly solid, containing iron and nickel as well as sulphur. It does not generate a magnetic field.

Crust
Mars's crust appears to be thicker than that of Earth's, especially in areas of prior volcanic activity.

A thin atmosphere

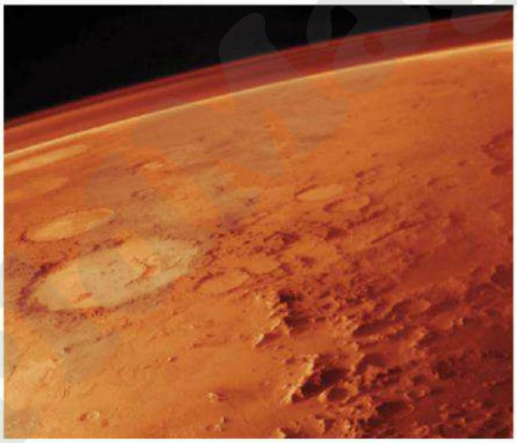


Upper atmosphere
Also known as the thermosphere, this layer is heated by the Sun. The lack of a magnetic field means that the gases separate out into space.

Middle atmosphere
In the middle atmosphere, the Martian jet stream swirls the surface dust and gives the sky its orange colour.

Lower atmosphere
The atmosphere contains 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon and traces of elements such as methane.

Thin ice clouds
Strong winds sweeping off Mars's polar ice caps, along with atmospheric sublimation of carbon dioxide, help create these thin ice clouds.



This image, taken by the Viking Orbiter from low orbit, shows the thin layer of Mars's atmosphere – less than one per cent the thickness of Earth's atmosphere

On the surface

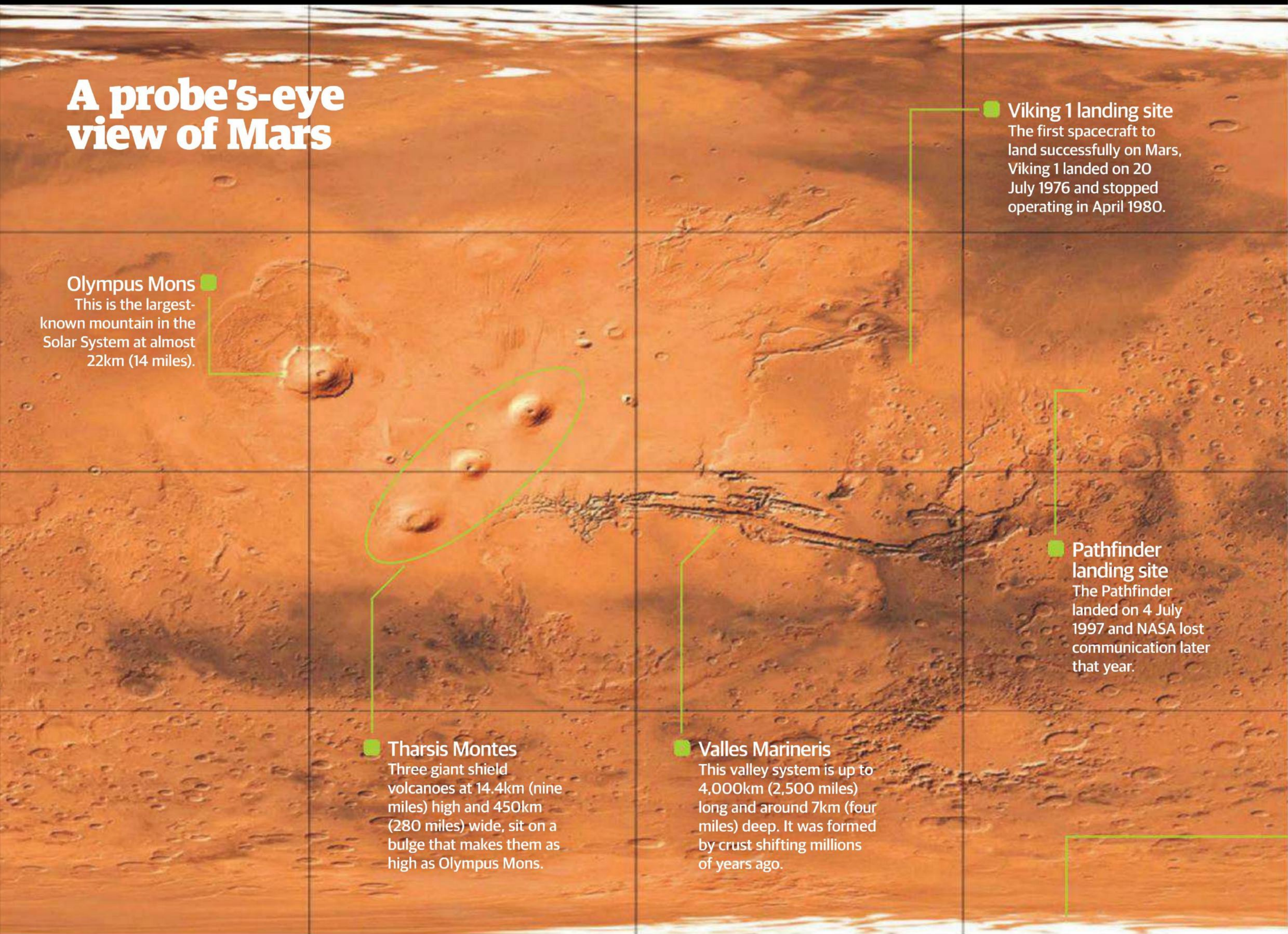
Mars has a lot of geographical similarities with Earth, but there's a reason why we haven't found life there… yet

Thanks to the many images sent back from various probes, we know that Mars has a lot of interesting geographical features. The biggest one is that Mars has incredibly different northern and southern hemispheres. Most of the northern hemisphere is lower in elevation than the southern one (up to six kilometres or four miles lower). It also has far fewer impact craters, and is much smoother and uniform all over. Finally, the crust on the northern hemisphere appears to be much thinner than the southern hemisphere's. While astronomers aren't sure of the reasons behind this dichotomy, it involves the three main forces that have influenced the planet's surface: volcanic activity, tectonics and impacts.

Some of the most striking features on Mars's surface are its mountains – which are all inactive volcanoes. The western edge of the southern hemisphere contains two different areas – the Tharsis bulge and the Elysium volcanic complex – each of which contain several volcanoes. The Tharsis bulge covers about 25 per cent of the planet's surface and lies seven to ten kilometres (four to six miles) above it. This includes Mons Olympus, a shield volcano that is the largest mountain in the Solar System.

Scientists were sure that Mars didn't have plate tectonics like Earth – until this year. That's when we discovered that there are in fact tectonics at work. Not only do features like steep cliffs and the flat walls of canyons show faults at work, but so do the fact that Mars's volcanoes are concentrated in two different areas. The huge valley system known as the Valles Marineris is the deepest in the Solar System and takes up a quarter of the planet's circumference. It's also a plate boundary, with horizontal

A probe's-eye view of Mars



Viking 1 landing site
The first spacecraft to land successfully on Mars, Viking 1 landed on 20 July 1976 and stopped operating in April 1980.

Olympus Mons
This is the largest-known mountain in the Solar System at almost 22km (14 miles).

Pathfinder landing site
The Pathfinder landed on 4 July 1997 and NASA lost communication later that year.

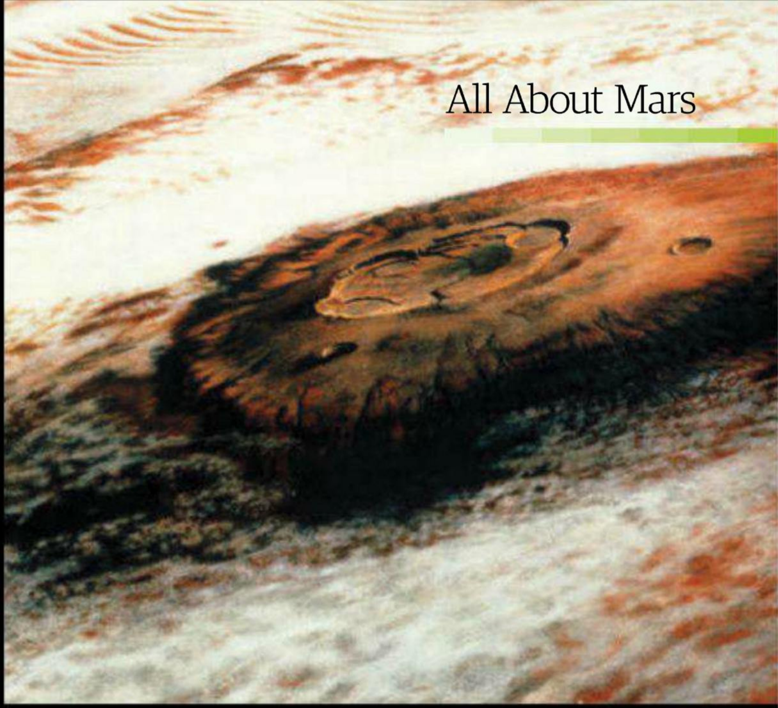
Tharsis Montes
Three giant shield volcanoes at 14.4km (nine miles) high and 450km (280 miles) wide, sit on a bulge that makes them as high as Olympus Mons.

Valles Marineris
This valley system is up to 4,000km (2,500 miles) long and around 7km (four miles) deep. It was formed by crust shifting millions of years ago.

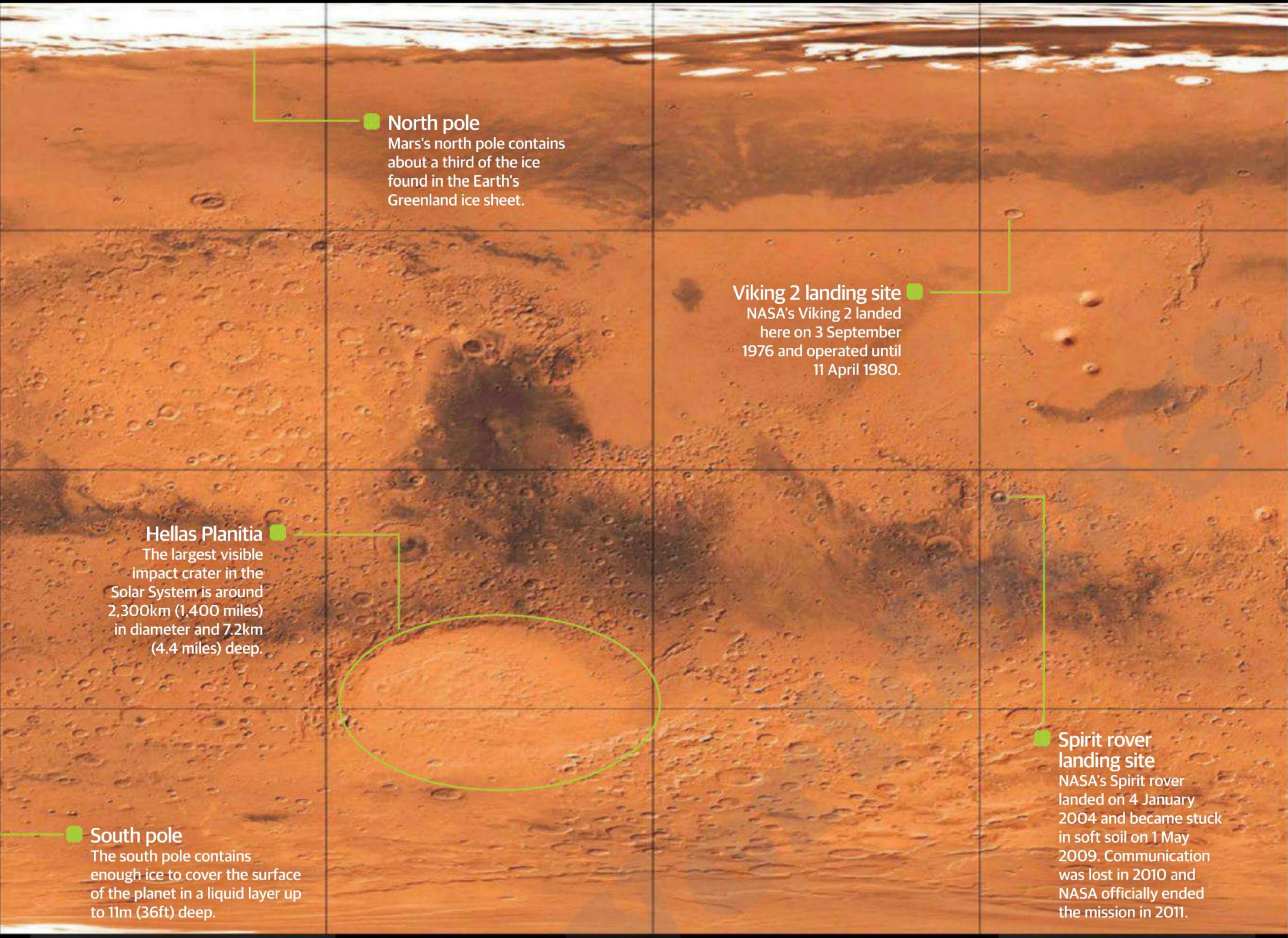
movement along the plates. With just one known fault as opposed to many on Earth, some believe that Mars's tectonic system is much younger.

Impact craters and basins are prevalent in Mars's southern hemisphere. The Hellas basin is the largest of these at 1,800 kilometres (1,100 miles) in diameter. The largest basins are believed to date back to a period of heavy bombardment about 3.8 billion years ago. They show evidence of erosion and also contain a lot of regolith, or soil deposits. The smaller craters are younger, and look a lot like the Moon's impact craters. Mars has many different types of craters thanks to erosion, deposits and volcanic activity. They also contain ejecta blankets – flows formed in the soil after an impact melts ice under the planet's surface.

Mars is believed to have ice underneath its surface – and there are also ice caps at the poles, the amount of which changes depending on the seasons. Because Mars has a similar tilt to the Earth, it does have four seasons – they're just longer and of varied lengths. Temperatures can get as low as minus 143 degrees Celsius (minus 225 degrees Fahrenheit) at the ice caps in the winter. The ice beneath the surface freezes and melts depending on the temperature. The atmospheric pressure on Mars is much lower than the Earth's, and it's so thin that there is very little to block the surface from the Sun's heat. There are ice clouds, probably caused when the wind kicks up dust, while one of the Red Planet's biggest weather features is dust storms, which can last up to a month.



Despite its thin atmosphere, Mars does have a layer of ice-water clouds, although the blanket lies below the planet's tallest volcano, Olympus Mons. A wave cloud due to ripples in the atmosphere is also visible.



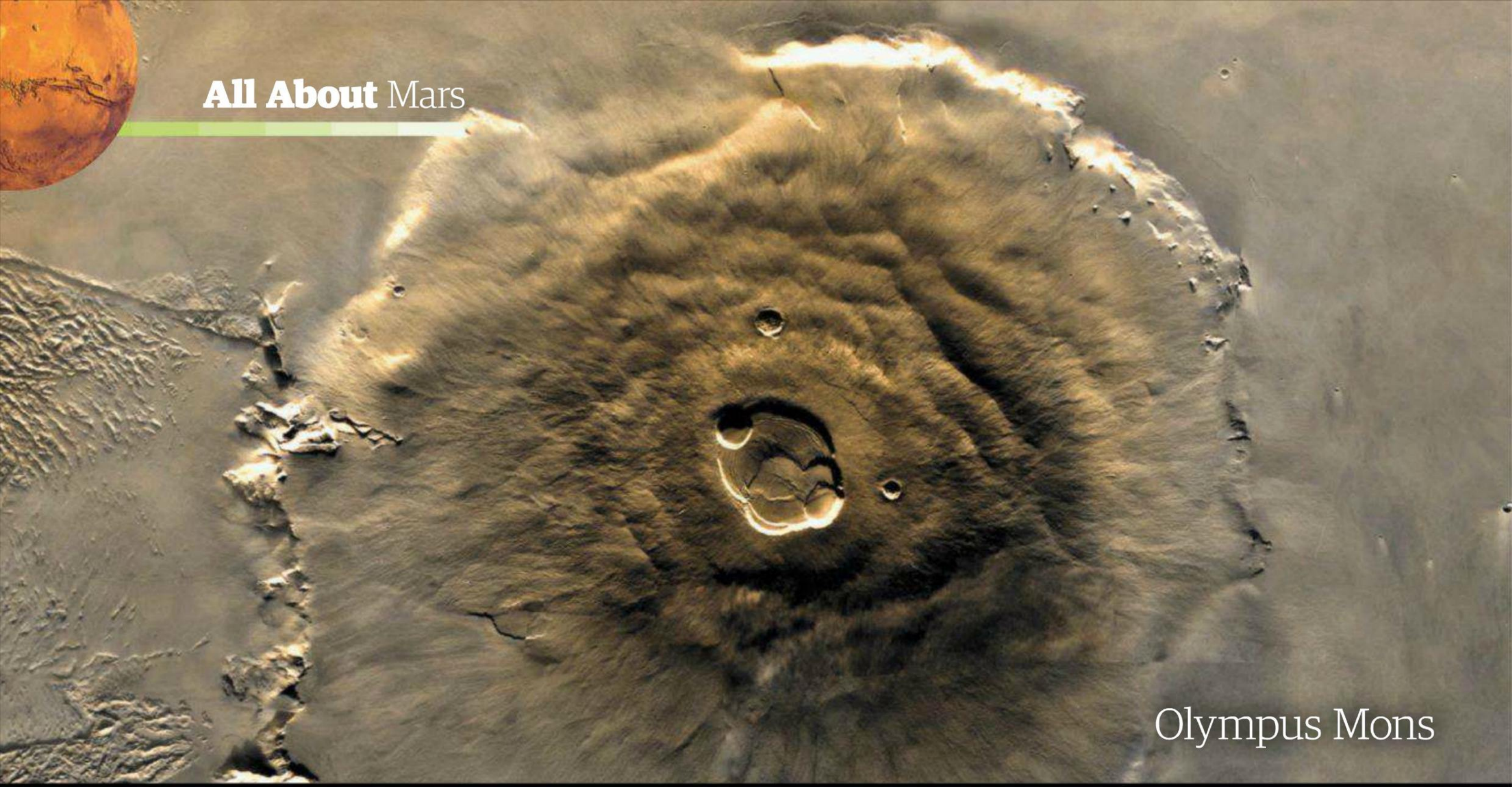
North pole
Mars's north pole contains about a third of the ice found in the Earth's Greenland ice sheet.

Viking 2 landing site
NASA's Viking 2 landed here on 3 September 1976 and operated until 11 April 1980.

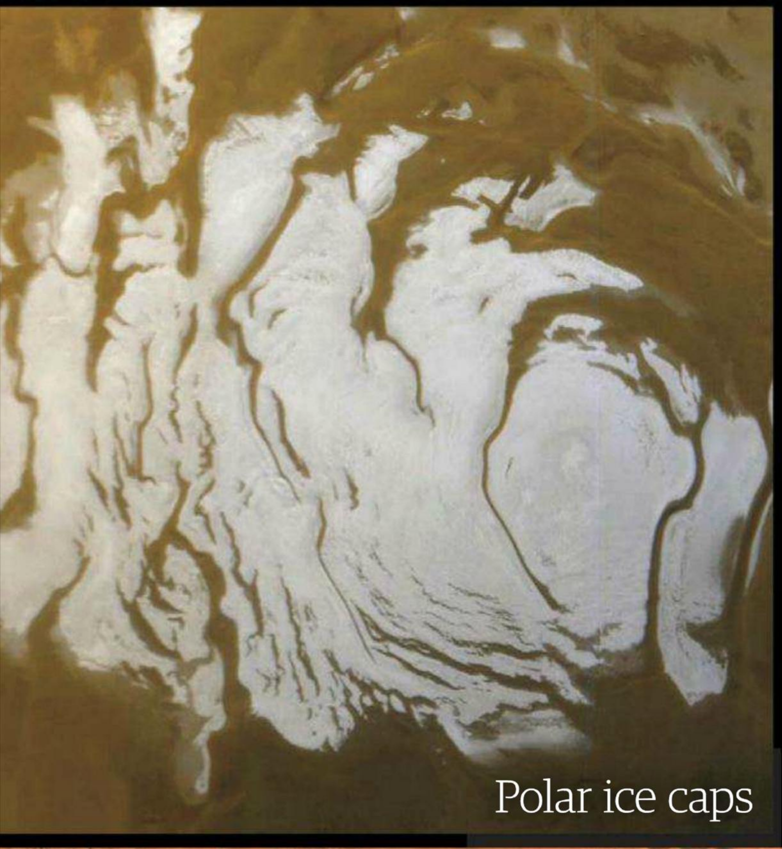
Hellas Planitia
The largest visible impact crater in the Solar System is around 2,300km (1,400 miles) in diameter and 7.2km (4.4 miles) deep.

South pole
The south pole contains enough ice to cover the surface of the planet in a liquid layer up to 11m (36ft) deep.

Spirit rover landing site
NASA's Spirit rover landed on 4 January 2004 and became stuck in soft soil on 1 May 2009. Communication was lost in 2010 and NASA officially ended the mission in 2011.



Olympus Mons



Polar ice caps

Canyons, craters and deserts

Mars is home to some of the largest planetary features in the Solar System

Olympus Mons
Olympus Mons is the tallest known mountain in the Solar System at 22km (14 miles) high. It's more than twice the size of Mount Everest and is an extinct volcano.

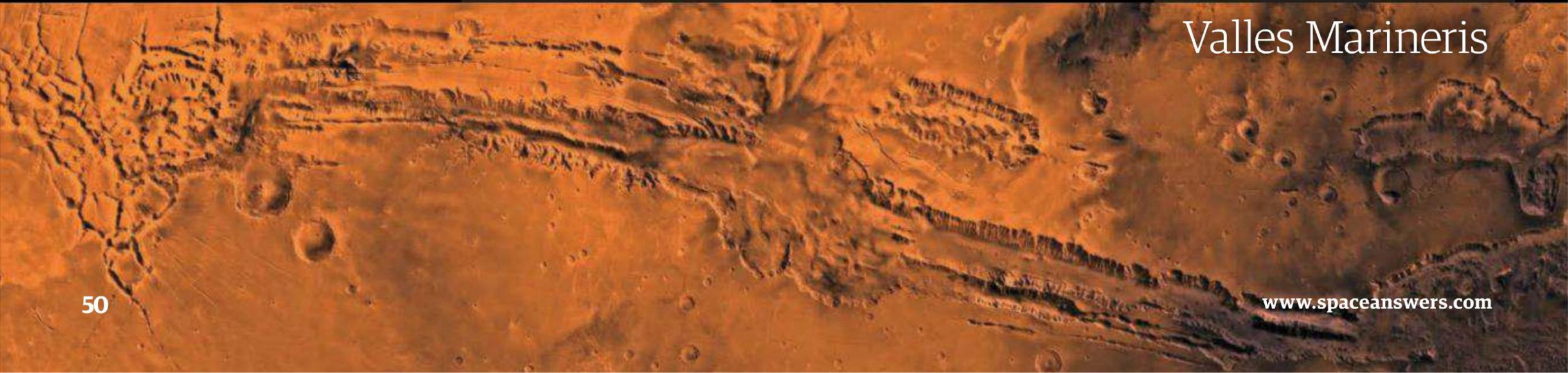
Polar ice caps
This polar ice cap on the southern end of Mars grows and wanes each year depending on the season. It is made up of both water ice and dry ice (frozen carbon dioxide).

Valles Marineris
Valles Marineris is a system of canyons located along the equator of Mars and covers almost 25 per cent of the planet's circumference. It is around 7km (four miles) deep, 200km (124 miles) wide and 4,000km (2,500 miles) long. On Earth, that would be the distance between New York and Los Angeles.

Water erosion
Reull Vallis is one of the valleys on Mars that look as if they may have been carved out by water movement. Many of these valleys contain grooves on their floors that may be rich in ice.

Sand dunes
Regolith – a mix of soil, sand, dust and broken rocks – has drifted into dunes on Mars's surface. We once thought they were stationary, but observations have shown that the dunes actually move due to prevailing winds.

Hellas Basin
The Hellas Basin is one of the biggest impact craters in the Solar System. At 2,300km (1,400 miles) in diameter, it is wider than the state of Texas.



Valles Marineris

Water erosion

Sand dunes

Hellas Basin

Mars by numbers

Fantastic figures and surprising statistics about the Red Planet

2,300km

The diameter of Mars's Hellas Basin is the same as the diameter of Pluto

2

Mars has two known satellites: the moons of Phobos and Deimos

271 years and 221 days

How long it would take you to get to Mars from Earth if you could drive there in a car at 97km/h (60mph)

14.5

Travelling at a speed of 14.5 miles per second compared to the Earth's 18.5 miles per second, Mars is slower to orbit the Sun

687 Earth days

A year on Mars is 687 Earth days, while a day on Mars is equivalent to 1.026 Earth days

37.5%

Gravity on Mars as a percentage of Earth's. If you could visit, you could jump three times as high as you can on our planet

Exploring Mars

The failure rate for exploring Mars has been high

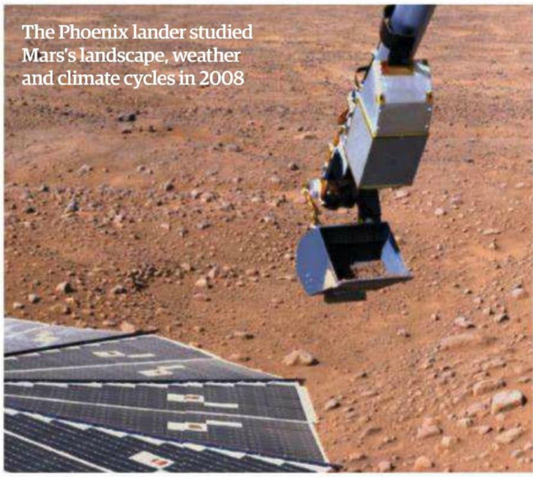
The Soviet Union, not the United States, was the first country to attempt a Mars exploration – but it was unsuccessful. The Mars 1M was just the first of many failed attempts to visit Mars. Since that first attempt in 1960, 43 different spacecraft have tried and only 14 of them completed their missions. Mars 1M had a launch failure, but other probes have been the victims of communication problems, computer malfunctions and even the planet itself. It's been so difficult to get to Mars that some have dubbed the challenge the "Martian curse", and one journalist in the United States jokingly said that there must be a "Galactic Ghoul" hindering our exploration efforts. So why has it proved so difficult to get there?

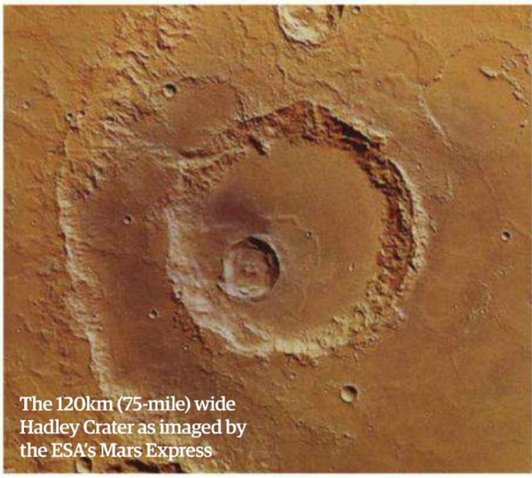
It takes a spacecraft about seven months on average to travel the 225 million kilometres (140 million miles) to Mars. Once it reaches the planet, if the orbiter has a lander then it must successfully separate and have the lander touch down gracefully on the surface. And Mars can be unpredictable. Things like dust storms and soft soil have impeded landers, for example. But we do have to remember that most of total failures were early in our space exploration history. While there have been some memorable recent failures, including the 1999 Mars Climate Orbiter, which was pure human error. In that case, a contractor used imperial units instead of metric, which caused the probe's rocket to shut down early and send it crashing into the planet.

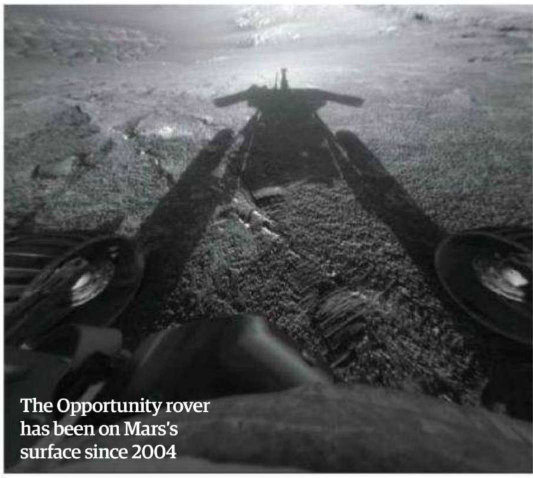
Currently there are three orbiters around Mars: the Mars Odyssey and Mars Reconnaissance Orbiter, both from NASA, and the European Space Agency's Mars Express. The Opportunity rover has been on the surface since 25 January 2004 and Curiosity recently joined it. Despite the high failure rate, we'll surely continue to explore the Red Planet. It's just too fascinating to keep away. ●

MSL launches atop a Atlas V rocket on 26 November 2011

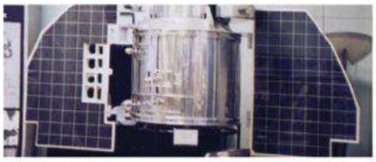
> "It takes a spacecraft about seven months to travel the 225 million kilometres to Mars"

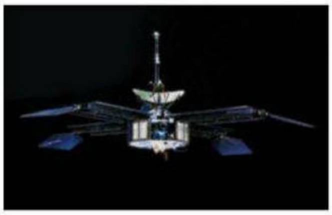

The Phoenix lander studied Mars's landscape, weather and climate cycles in 2008

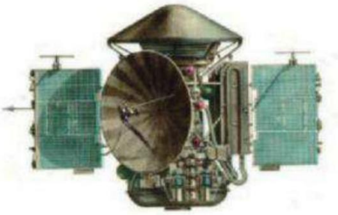

The 120km (75-mile) wide Hadley Crater as imaged by the ESA's Mars Express


The Opportunity rover has been on Mars's surface since 2004

Major missions

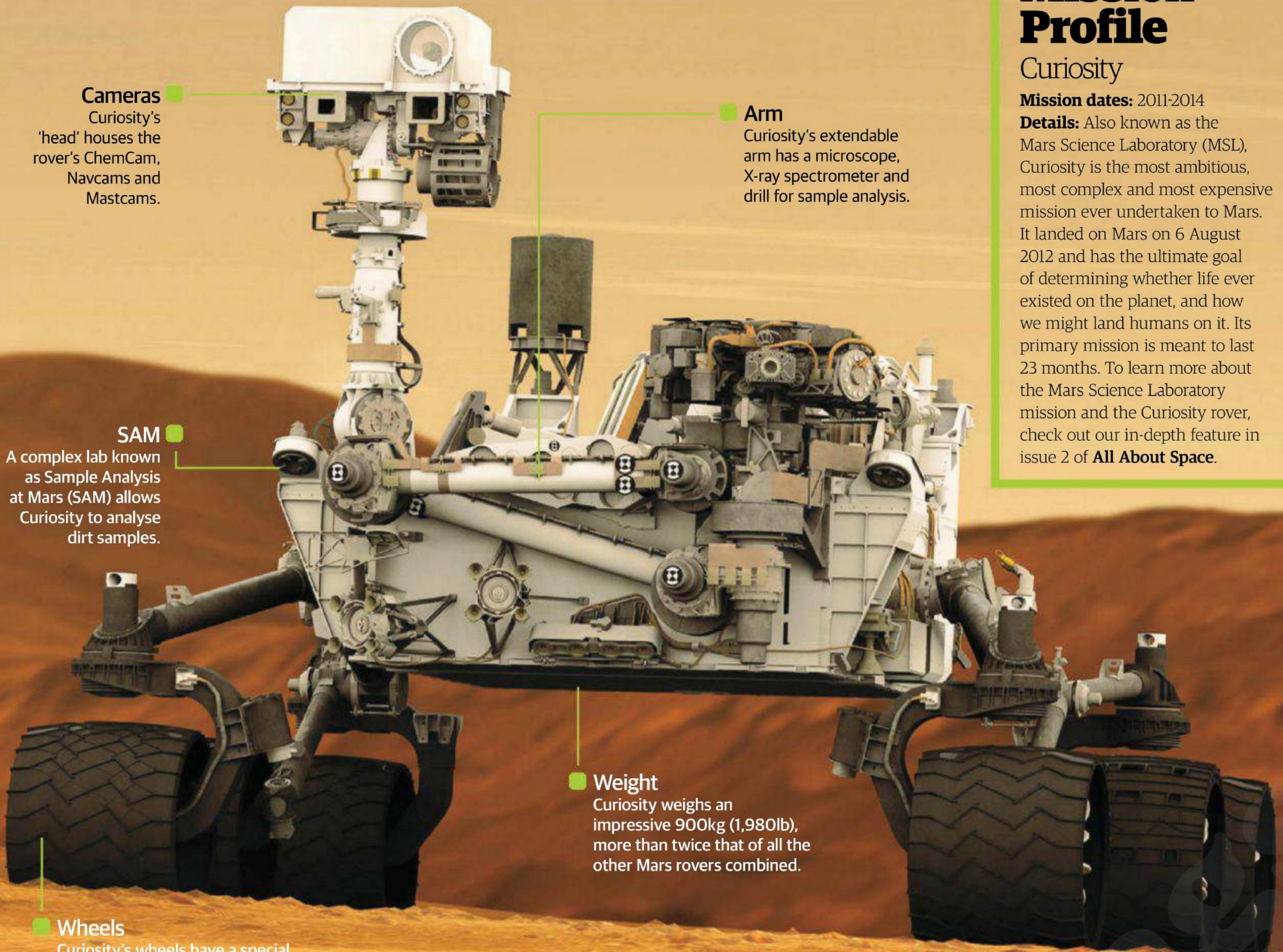

Mars 1M
Oct 1960
These Soviet missions were the first in the quest to explore Mars. Mars 1M No 1 experienced a launch failure on 10 October 1960. Mars 1M No 2 met the same fate.


Mariner 4
28 Nov 1964-21 Dec 1967
Mariner 4 performed the first flyby and returned the first colour images of Mars. These were also the first images taken of another planet from deep space.


Mars 2 & 3
19 May 1971-22 Aug 1972
The Soviet-built Mars 2 became the first spacecraft to land – or rather crash – into the surface of the planet. Mars 3 had a soft landing on 2 December 1971.

Viking 1 & 2
20 Aug 1975-13 Nov 1982
Viking 1 landed softly and fully completed its mission. It also held the record for longest Mars mission until the Opportunity rover.

> “Despite the high failure rate, we’ll surely continue to explore the Red Planet”



Cameras
Curiosity’s ‘head’ houses the rover’s ChemCam, Navcams and Mastcams.

Arm
Curiosity’s extendable arm has a microscope, X-ray spectrometer and drill for sample analysis.

SAM
A complex lab known as Sample Analysis at Mars (SAM) allows Curiosity to analyse dirt samples.

Weight
Curiosity weighs an impressive 900kg (1,980lb), more than twice that of all the other Mars rovers combined.

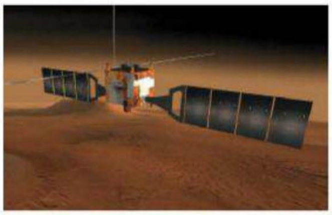
Wheels
Curiosity’s wheels have a special Morse code track that allows scientists to accurately measure how far the rover has travelled.

Mission Profile

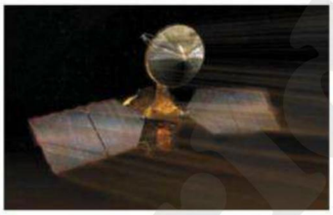
Curiosity

Mission dates: 2011-2014
Details: Also known as the Mars Science Laboratory (MSL), Curiosity is the most ambitious, most complex and most expensive mission ever undertaken to Mars. It landed on Mars on 6 August 2012 and has the ultimate goal of determining whether life ever existed on the planet, and how we might land humans on it. Its primary mission is meant to last 23 months. To learn more about the Mars Science Laboratory mission and the Curiosity rover, check out our in-depth feature in issue 2 of **All About Space**.

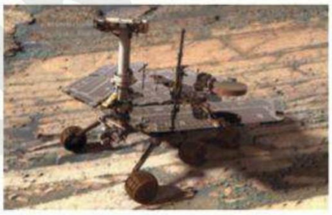
Mars Polar Lander
3 Jan 1999-3 Dec 1999
The Mars Polar Lander was meant to perform soil and climatology studies on Mars, but NASA lost communication with it and it’s believed it crashed.



Mars Express Orbiter
2 Jun 2003-present
The ESA’s first planetary mission consisted of the Beagle 2 lander and the Mars Express Orbiter, with the latter still operational today.



Beagle 2
2 Jun 2003-19 Dec 2003
The Beagle 2 lander was lost six days before it was due to enter the Martian atmosphere. Attempts were made to contact it, but these ended in failure.



Opportunity
7 Jul 2003-present
Opportunity was a rover launched shortly after its twin, Spirit, by NASA. While Spirit ceased communications in 2010, Opportunity is still going strong.

Neil Armstrong descends the Lunar Module's ladder on his way to the Moon's surface

Neil Armstrong and the first moonwalk

Written by Dave Roos

The late Neil Armstrong will forever be remembered as the first human being to set foot on the Moon. **All About Space** looks back at that historic Apollo 11 moonwalk

On 21 July 1969 (UTC), 530 million television viewers sat transfixed by the first grainy, black-and-white transmission from the surface of the Moon. At 109 hours, 24 minutes and 15 seconds into the Apollo 11 mission, Neil Armstrong, the soft-spoken mission commander, climbed down the ladder of the Lunar Module and became the first human being to place his foot on celestial soil. Armstrong, who died in 2012 at the age of 82, was ready with his now famous pronouncement, "That's one small step for man; one giant leap for mankind."

The logistics of the journey were staggering. It required a three-stage Saturn V rocket, a slingshot around the Moon and a final descent in a tiny capsule, barely avoiding a rock-strewn field to land safely on the edge of the Sea of Tranquillity. Inside the landing module, nicknamed the 'Eagle', were Armstrong and his co-pilot Edwin E 'Buzz' Aldrin, Jr. Their third comrade, Michael Collins, was 100 kilometres (62 miles) overhead, orbiting in the Command/Service Module.

The men had rehearsed every step of their eight-day journey, including the experiments they would conduct during the moonwalk, known in NASA circles as extra-vehicular activity (EVA). But even with their extensive training, the Moon was very much terra incognita. Would the dust on the lunar surface be so fine and deep that they would sink into it like quicksand? Would their spacesuits, designed to keep the astronauts cool in the Moon's 100 degree Celsius (212 degree Fahrenheit) temperatures, work? To ensure the astronauts' safety, this first moonwalk would be quick – just two and a half hours of scientific exploration, photo documentation and a chat with the President.

The two astronauts knew that the mission could be aborted at any time. That's why Armstrong's first act, before planting the flag or posing for a photo, was to grab the closest hunk of Moon rock as a contingency sample. If nothing else worked, at least they would have something to show the eager NASA geologists back home.

15 minutes after Armstrong made his fateful 'leap', Aldrin stepped from the landing module hatch and descended to the surface. The two men snapped photos of the landing site and described the feel of the lunar surface and the effect of the module's descent engines on the lunar dust.

Next, Armstrong read from a plaque mounted on the Lunar Module ladder. The ladder, and the plaque, would remain on the Moon when the rest of the craft eventually brought the astronauts back to rendezvous with Collins. Armstrong read the plaque to the rapt millions back home: "Here men from planet Earth first set foot upon the Moon. July 1969 AD. We came in peace for all mankind."

Photo documentation was a critical focus of the Apollo 11 mission. Armstrong and Aldrin were armed with high-end Hasselblad 70mm still cameras, a 16mm movie camera, plus super-wide focus lenses and a 35mm stereoscopic close-up camera. The men were on orders to photograph or film nearly every aspect of the moonwalk: from panoramic vistas to extreme closeups of the lunar surface.

The television camera was equally, if not more, important than the still cameras. Not only was the live TV footage 'proof' of NASA's momentous achievement, but every frame would be recorded and analysed back home for clues to the physical and environmental properties of the Moon. Look how the dust settles. See how the soil colour changes after it is compressed by a boot. Check out Aldrin's stiff gait as he tries to bunny hop in his bulky suit. After reading the plaque, Armstrong carried the TV camera about 25 metres (80 feet) from the landing module so it would have a clear, wide shot of everything the astronauts did.

One focus of the TV footage was the moonwalkers' mobility. Aldrin was the chief subject of these tests, which show the former Air Force pilot running, skipping, hopping and cutting sharply from left to right as he describes the ease or difficulty of each manoeuvre. Aldrin was also assigned the tasks of kicking lunar soil to evaluate its trajectory.

The planting of the American flag has been a flashpoint for conspiracy theorists who shout that a flag cannot 'wave' in a vacuum. That's true, which is why the one metre by 1.5 metre (three foot by five foot) flag was held open by a telescopic horizontal rod. The astronauts struggled to open the rod completely, which gave the flag a slightly ruffled appearance. The men also received a brief congratulatory phone call from President Richard Nixon, who described the feelings of those watching below. "For one priceless moment in the whole history of man," said Nixon, "all the people on this Earth are truly one."

But most of the work of that first moonwalk was dedicated to scientific experimentation. Armstrong collected 22 kilograms (48.5 pounds) of samples containing rocks, pebbles and fine lunar dust. Aldrin set up a solar wind collector made of aluminium foil. The foil was exposed for 77 minutes and it captured the first measurement of the solar particle stream outside of the Earth's magnetic field.

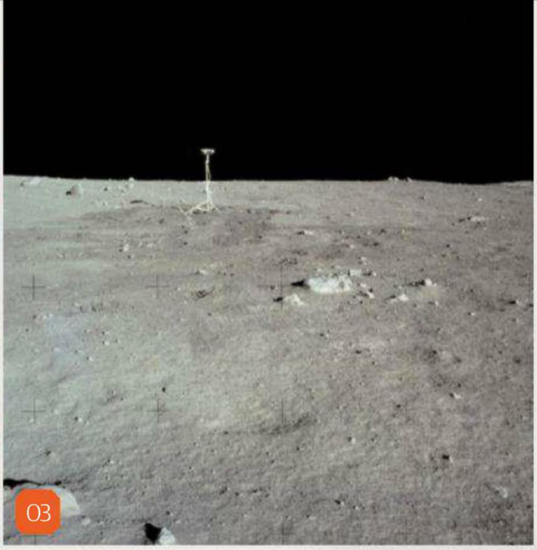
The men installed a seismometer that would beam back information about 'moonquakes' and give clues to the internal structure of the rocky orb. They also set up a special mirror called a lunar ranging retroreflector that would be used by Earth telescopes to bounce back long-range laser beams. The lasers would give the first hyper-accurate measurements of the Moon's distance from the Earth and how fast it is drifting away from us (38 millimetres or 1.5 inches annually).

Once the experiments were deployed, the famously by-the-books Armstrong momentarily veered from the game plan. Moving quickly across the lunar surface, he bounded to the nearby Little West Crater to snap a last-minute panoramic shot of its sloping interior. At a distance of 60 metres (196 feet) from the Lunar Module, this is the farthest either man strayed during the entire moonwalk.

At over 111 hours and 35 minutes into their mission, and only two hours and 32 minutes after Armstrong popped the hatch on the Lunar Module, the commander sealed it shut again. After some rest, the men would begin their journey home, ending with a splashdown in the Pacific. ■

> "For one priceless moment in the whole history of man," said Nixon, "all the people on this Earth are truly one"

02



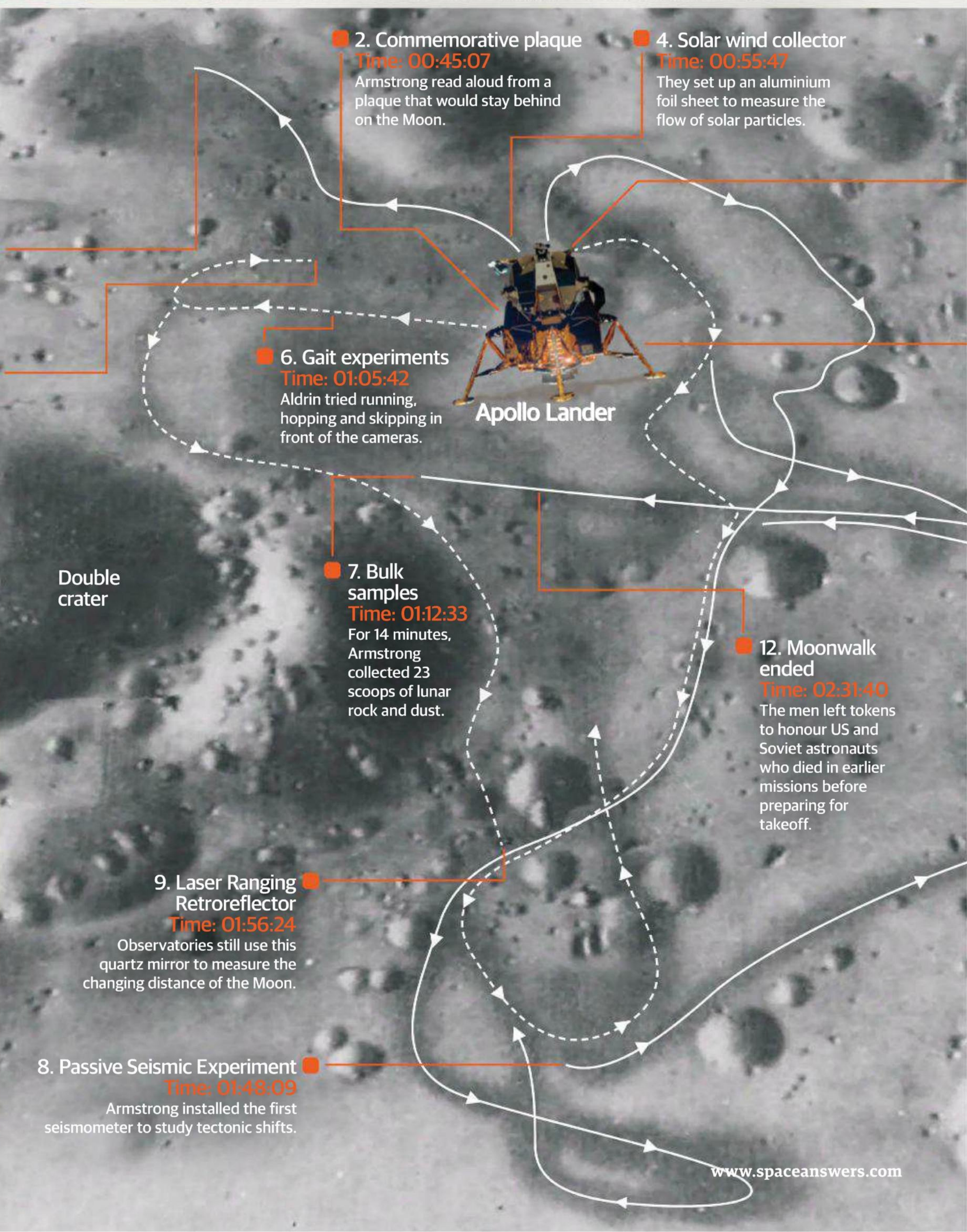
03

04

The first moonwalk explained

—— Neil Armstrong route

- - - Buzz Aldrin route



2. Commemorative plaque
Time: 00:45:07
Armstrong read aloud from a plaque that would stay behind on the Moon.

3. TV camera
Time: 00:55:20
Armstrong positioned the TV camera close to the Lunar Module to capture the historic EVA.

4. Solar wind collector
Time: 00:55:47
They set up an aluminium foil sheet to measure the flow of solar particles.

5. Planting the American flag
Time: 01:02:20
The planting was almost a disaster. The flagpole didn't drive deep enough into the soil and the support pole wouldn't open properly.

6. Gait experiments
Time: 01:05:42
Aldrin tried running, hopping and skipping in front of the cameras.

7. Bulk samples
Time: 01:12:33
For 14 minutes, Armstrong collected 23 scoops of lunar rock and dust.

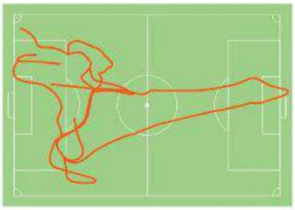
8. Passive Seismic Experiment
Time: 01:48:09
Armstrong installed the first seismometer to study tectonic shifts.

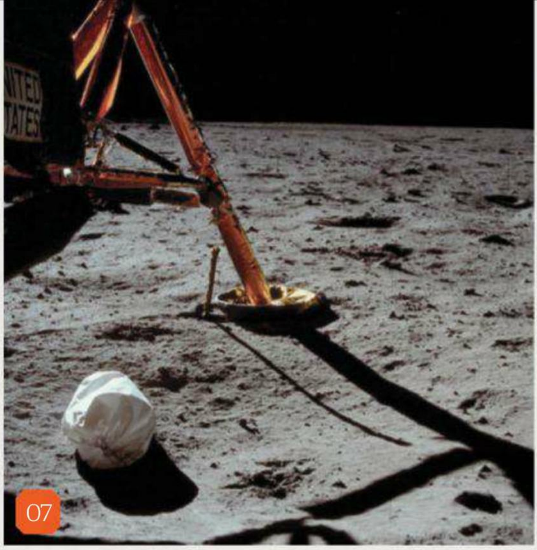
9. Laser Ranging Retroreflector
Time: 01:56:24
Observatories still use this quartz mirror to measure the changing distance of the Moon.

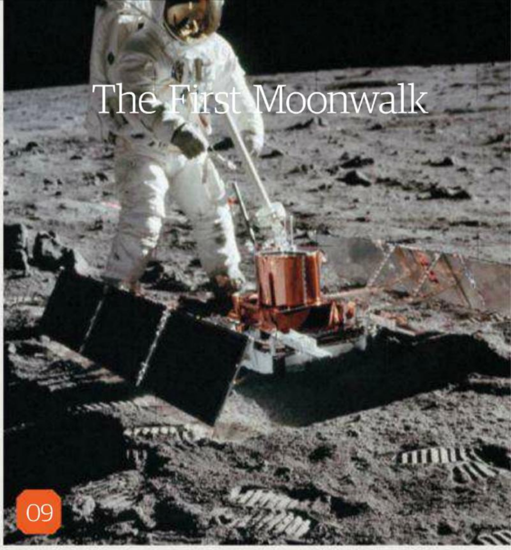
12. Moonwalk ended
Time: 02:31:40
The men left tokens to honour US and Soviet astronauts who died in earlier missions before preparing for takeoff.

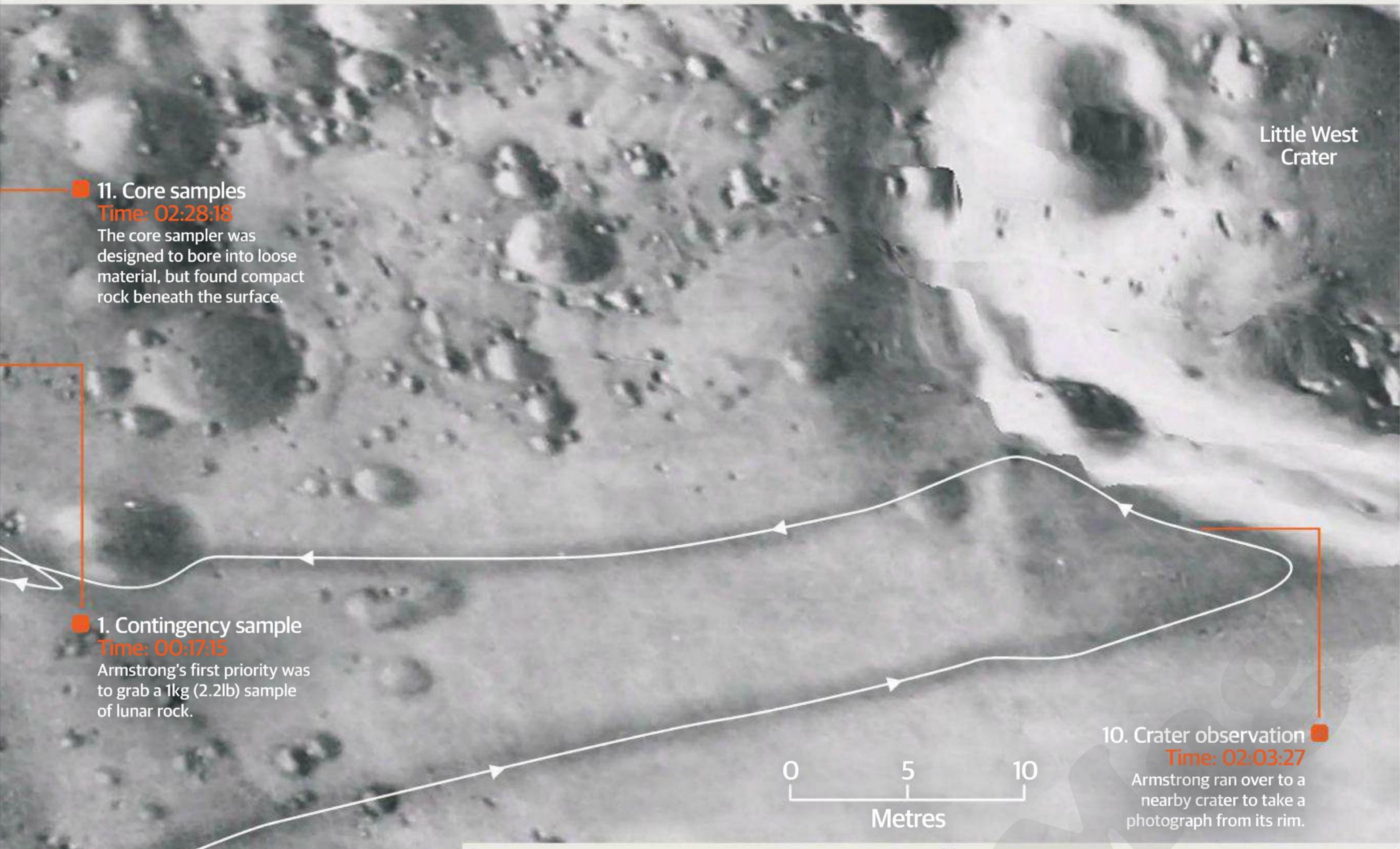
Distance covered

In their two and a half hours on the lunar surface, Armstrong and Aldrin never strayed more than 60 metres (196 feet) from the lunar module – less than the length of a football pitch. The fear was that the astronauts' water-cooled spacesuits would run out of H_2O, leaving them exposed to 100°C (212°F) lunar temperatures.





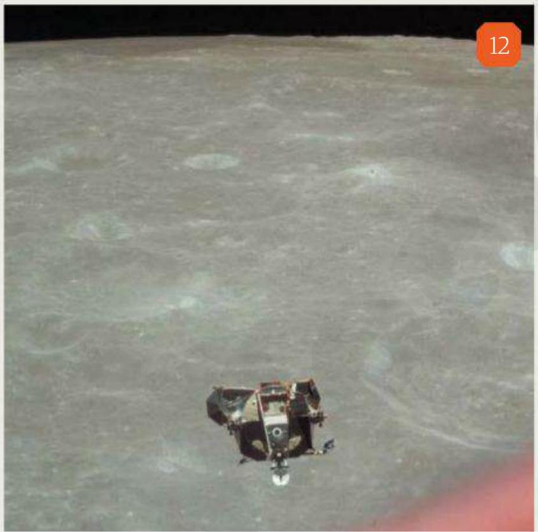


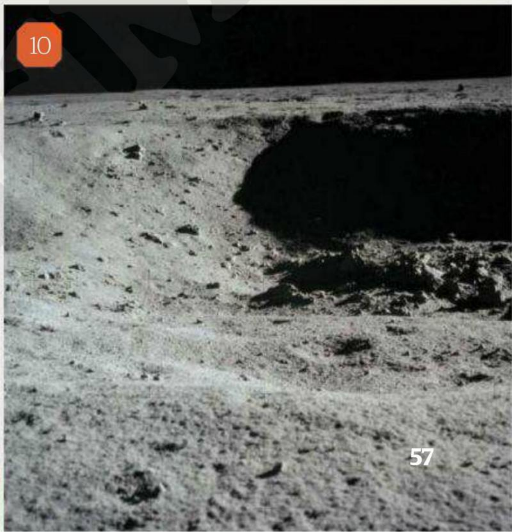


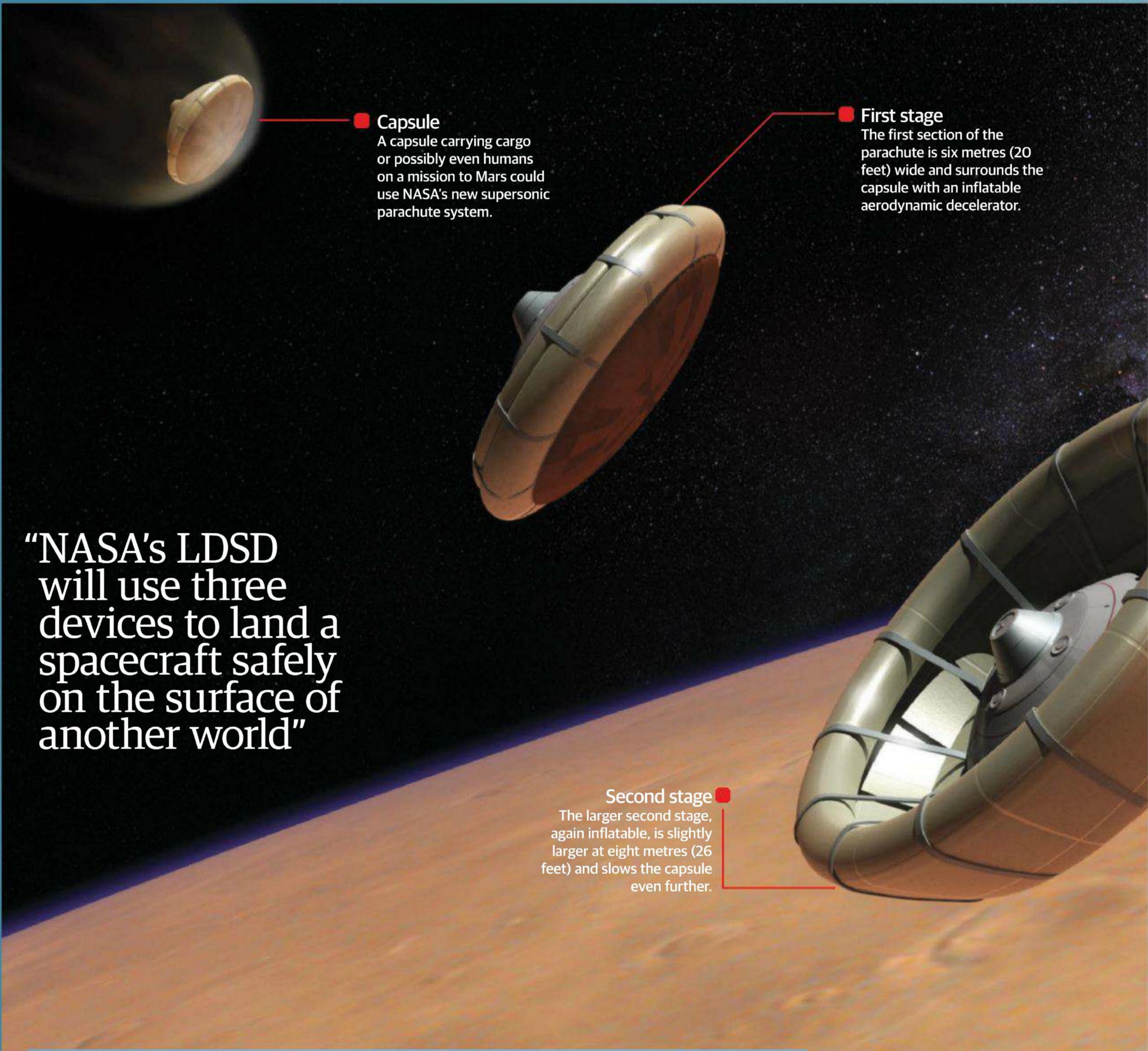
11. Core samples
Time: 02:28:18
The core sampler was designed to bore into loose material, but found compact rock beneath the surface.

1. Contingency sample
Time: 00:17:15
Armstrong's first priority was to grab a 1kg (2.2lb) sample of lunar rock.

10. Crater observation
Time: 02:03:27
Armstrong ran over to a nearby crater to take a photograph from its rim.







Capsule
A capsule carrying cargo or possibly even humans on a mission to Mars could use NASA's new supersonic parachute system.

First stage
The first section of the parachute is six metres (20 feet) wide and surrounds the capsule with an inflatable aerodynamic decelerator.

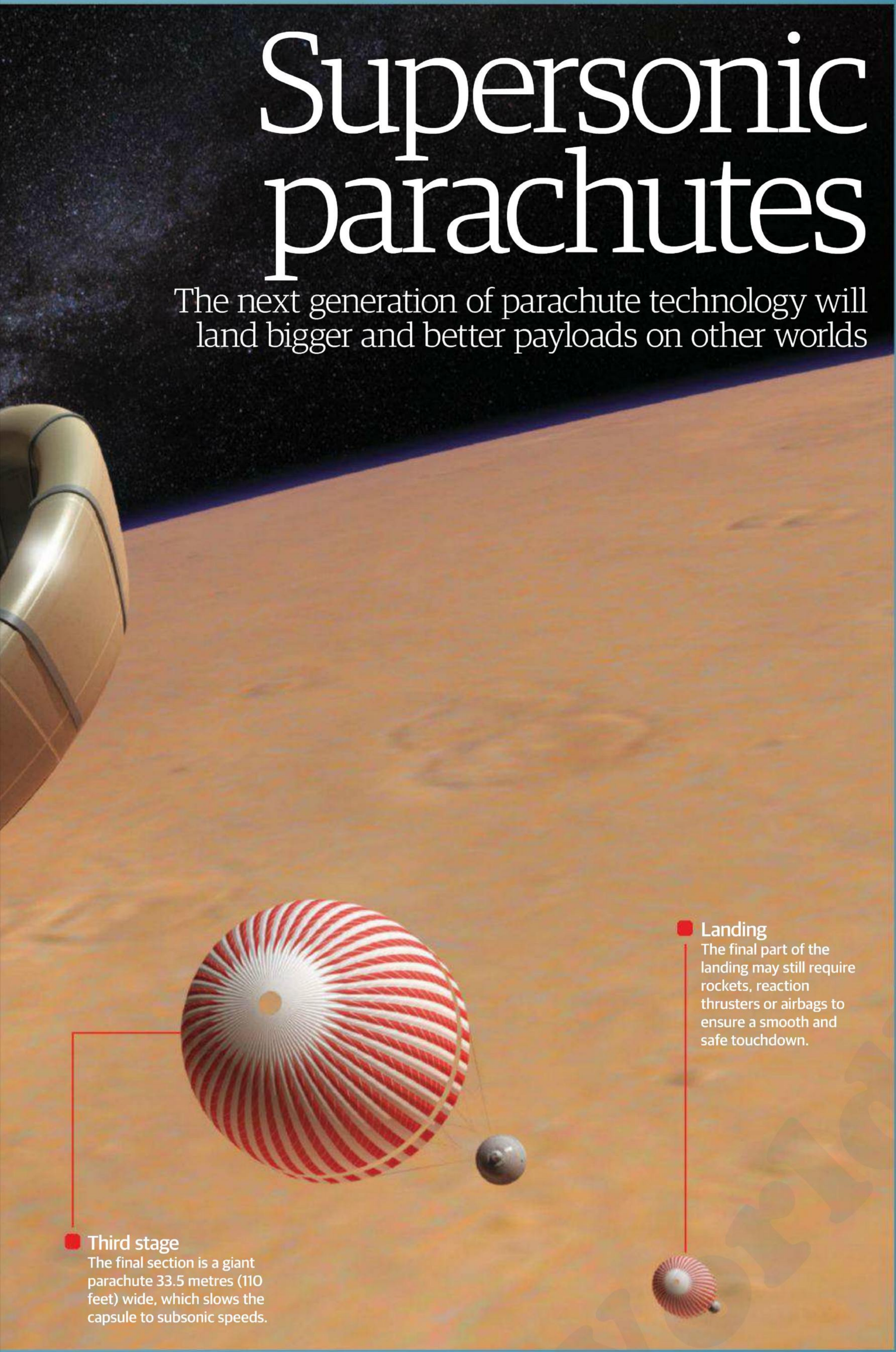
Second stage
The larger second stage, again inflatable, is slightly larger at eight metres (26 feet) and slows the capsule even further.

> "NASA's LDSD will use three devices to land a spacecraft safely on the surface of another world"

An inflatable decelerator being tested on rocket sled by NASA in mid-2012

Supersonic parachutes

The next generation of parachute technology will land bigger and better payloads on other worlds



Landing
The final part of the landing may still require rockets, reaction thrusters or airbags to ensure a smooth and safe touchdown.

Third stage
The final section is a giant parachute 33.5 metres (110 feet) wide, which slows the capsule to subsonic speeds.

When the Curiosity rover landed on Mars's surface on 6 August 2012 it employed the largest supersonic parachute to ever operate outside the confines of Earth, measuring a whopping 16 metres (52.5 feet) in diameter and being able to withstand a force of 29,500 kilograms (65,000 pounds). However, even this mammoth parachute wasn't enough to lower the rover all the way to the planet's surface, and it needed additional rocket boosters to touch it down safely. If we want to use a parachute to make it all the way to the surface of another world we're going to have to greatly enhance their capabilities, and NASA is in the process of doing just that.

Affectionately called the Low-Density Supersonic Decelerator (LDSD), NASA's next generation of supersonic parachutes will be unlike anything ever seen before. When landing on a world with an atmosphere, such as Mars, the atmospheric drag is a great way to slow down a spacecraft. For a single sheet parachute like that used on Curiosity, however, there's a limit to how much force it can handle, so NASA has been looking at a multiple component parachute to get large payloads safely and comparatively cheaply to the surface.

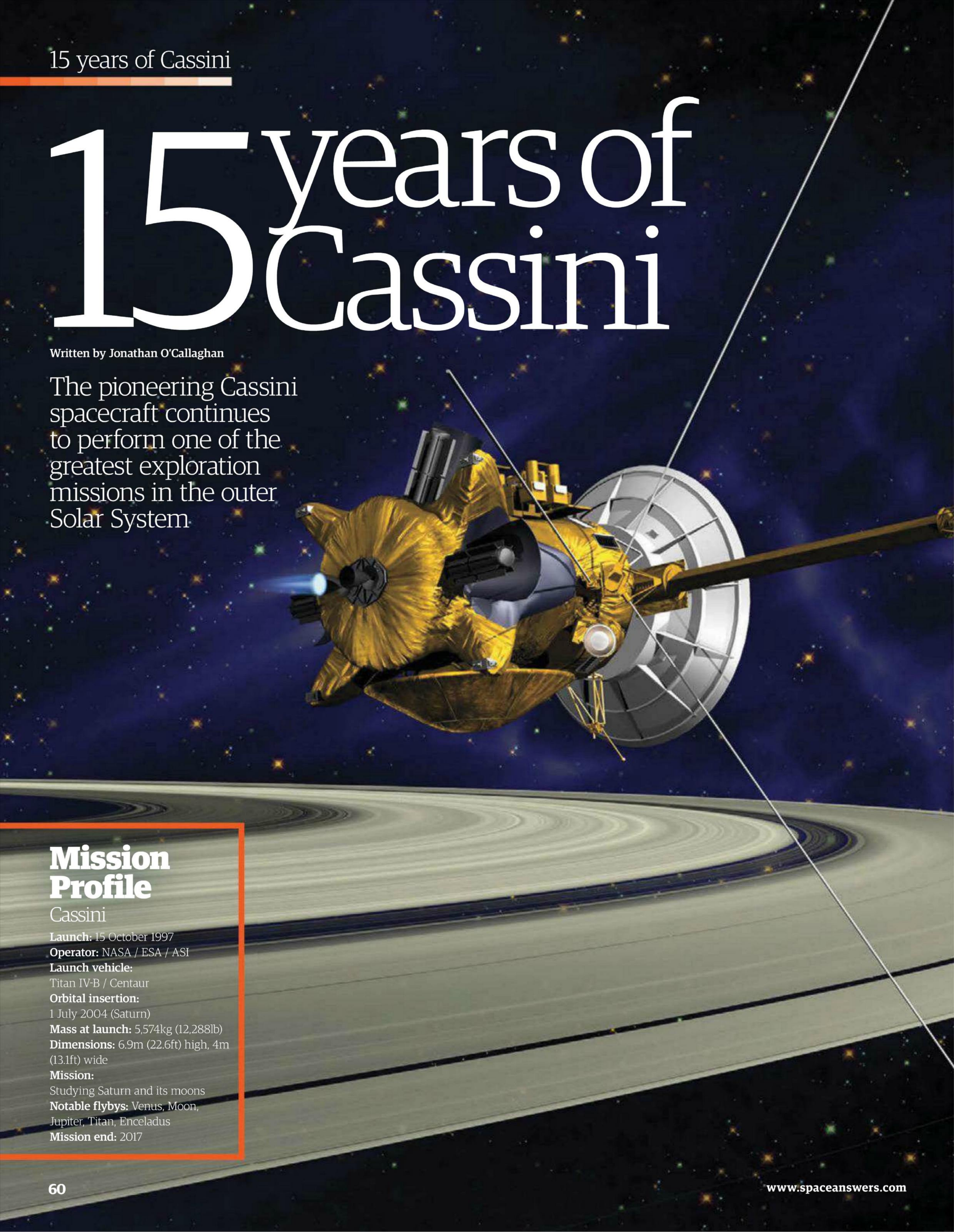
The LDSD will use three devices to land a spacecraft safely on the surface of another world. The first two sections are inflatable aerodynamic decelerators that will expand as the capsule passes through the atmosphere. These large, balloon-like pressure vessels, one measuring six metres (20 feet) in diameter and the other eight metres (26 feet), would surround the capsule and slow it from Mach 3.5 or higher to Mach 2. The last device will be a huge parachute 33.5 metres (110 feet) wide, which would slow the capsule to subsonic speeds (lower than the speed of sound).

It is estimated that this new type of supersonic parachute could double the payload capability of a capsule going to the surface of Mars, and improve landing accuracy from a margin of ten kilometres (6.2 miles) to just three kilometres (1.9 miles). In mid-2012, NASA conducted the first test of such a parachute system, using a rocket-powered sled to test its aerodynamic resilience. In the coming years NASA will test the parachute system in the atmosphere of Earth, in preparation for its use on Mars or potentially elsewhere in the Solar System with an atmosphere.

15 years of Cassini

Written by Jonathan O'Callaghan

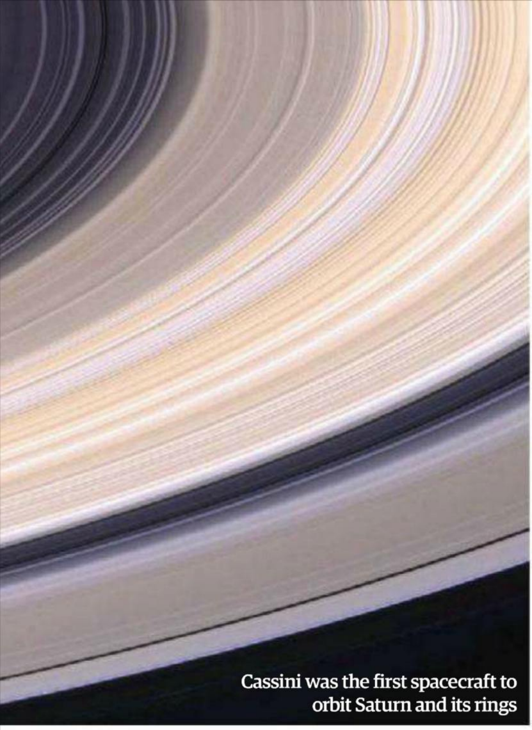
The pioneering Cassini spacecraft continues to perform one of the greatest exploration missions in the outer Solar System



Mission Profile

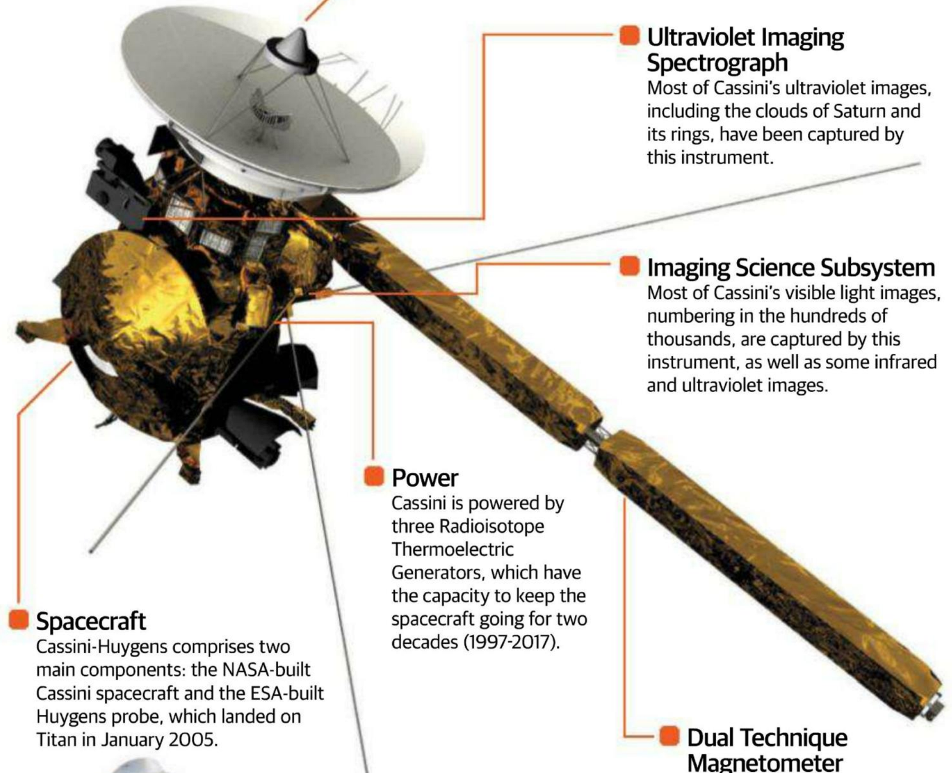
Cassini

Launch: 15 October 1997
Operator: NASA / ESA / ASI
Launch vehicle: Titan IV-B / Centaur
Orbital insertion: 1 July 2004 (Saturn)
Mass at launch: 5,574kg (12,288lb)
Dimensions: 6.9m (22.6ft) high, 4m (13.1ft) wide
Mission: Studying Saturn and its moons
Notable flybys: Venus, Moon, Jupiter, Titan, Enceladus
Mission end: 2017



Cassini was the first spacecraft to orbit Saturn and its rings

Inside the spacecraft



Communication
Cassini communicates with Earth by using its high-gain antenna. Its two low-gain antennas can also be used in emergency situations.

Ultraviolet Imaging Spectrograph
Most of Cassini's ultraviolet images, including the clouds of Saturn and its rings, have been captured by this instrument.

Imaging Science Subsystem
Most of Cassini's visible light images, numbering in the hundreds of thousands, are captured by this instrument, as well as some infrared and ultraviolet images.

Power
Cassini is powered by three Radioisotope Thermoelectric Generators, which have the capacity to keep the spacecraft going for two decades (1997-2017).

Spacecraft
Cassini-Huygens comprises two main components: the NASA-built Cassini spacecraft and the ESA-built Huygens probe, which landed on Titan in January 2005.

Dual Technique Magnetometer
Using this instrument Cassini is able to map the magnetosphere of Saturn and study the interaction of icy moons with it.

> "No spacecraft has increased our understanding of the Solar System like Cassini has"
>
> **Dr Linda Spilker, NASA JPL's Cassini project scientist**

Our knowledge of Saturn's system today is far greater than it has ever been. We know that the planet itself has some extreme weather at its poles, we know how fast it rotates, and we know the characteristics of its atmosphere. We also know a lot about its moons, from the wet and wonderful world of Titan to the mysterious Iapetus with its giant equatorial ridge. However, were it not for the Cassini-Huygens mission, much of our knowledge of the Saturnian system would remain hidden away.

Launched 15 years ago on 15 October 1997, the Cassini-Huygens spacecraft (to use its full name, although only the Cassini orbiter is still operative) has greatly increased our understanding of Saturn, and in some parts Jupiter, and its surrounding moons. It was, and is, a mission jointly operated by NASA, the ESA and ASI (Italian Space Agency) to further our understanding of Saturn and its surrounding system like never before. While its seven-year journey to the second-largest planet in our Solar System included flybys of Venus, the Moon and Jupiter, the crux of its mission has focused around Saturn, and after becoming the first spacecraft to orbit the planet in 2004 it continues to operate nominally, constantly returning new data and images.

The mission itself has been a resounding success and highlights the benefits of an international endeavour to explore space. "Cassini is one of the greatest unmanned missions ever," NASA JPL's Cassini project scientist Dr Linda Spilker told **All About Space**. "Cassini's discoveries have implications not only for the Saturn system, but by extension for the other outer planets, and their icy moons and rings, as well as exoplanets orbiting other stars."

Indeed, findings by the Cassini orbiter have significantly helped to increase our understanding of water formation on many other celestial bodies and, as Dr Spilker says, the importance of finding ice on other worlds. "Cassini's discoveries have expanded the envelope of potentially habitable zones in our Solar System with the discovery of a liquid water reservoir on Enceladus, and a liquid water ocean under Titan's icy crust."

Of all the observations Cassini has made in its mission so far, Dr Spilker highlights the discovery of jets of water and icy particles on Enceladus as one of the most significant. "This unexpected discovery completely changed our thinking about activity on small bodies, as Enceladus is only 500 kilometres [310 miles] in diameter. A heat source and compounds that include carbon, hydrogen, oxygen and nitrogen in the liquid water reservoir underneath Enceladus's south pole provide a potentially habitable environment far from the Sun."

In addition, the study of the Earth-like surface of Titan proved to be of huge significance, providing scientists with a look into an alien world that had many similarities to our own, and one that was the subject of the only ever landing in the outer Solar System. "The Huygens probe unveiled the surface of Titan for the first time," said Dr Spilker. "It revealed river channels and methane outgassing from the surface. Further Cassini explorations revealed north polar lakes, dunes, clouds and rainstorms on Titan." These continued observations brought about the realisation that methane on Titan plays the same role that water plays on Earth, adding to its Earth-like qualities. The likelihood of a liquid water ocean beneath its icy crust only heightened the intrigue, and has made Titan the predominant subject of Cassini's remaining five years of its mission.

"In the next five years Cassini will continue to follow seasonal change in the Saturn system, as well as follow up on new discoveries and continue to make additional discoveries," said Dr Spilker. "As the seasons change on Titan will the northern lakes begin to evaporate or remain unchanged? Will more storms develop in Titan's north polar region? Will a polar hood now form at Titan's south pole as winter approaches?" These are just some of the questions that the Cassini team hope their incredible spacecraft will answer before its mission ends in 2017.

However, even Cassini's finale will be magnificent, much like the rest of the mission. Dr Spilker told us what would make its final moments so exciting: "Cassini will dive between the innermost D ring and the top of Saturn's atmosphere for a series of 22 orbits. It will map Saturn's magnetic and gravity fields to a much higher order than was possible from more distant orbits. The magnetic field data may reveal the internal rotation rate of Saturn for the first time, something we do not yet know. We will also measure the mass of the rings for the first time, key to understanding their age and origin. This end of mission is planned so Cassini will not inadvertently impact either Titan or Enceladus."

Cassini's end in 2017 will bring with it a situation where, for the first time since the arrival of the Galileo spacecraft at Jupiter in 1995, the outer Solar System will be devoid of any spacecraft. The next - the ESA's JUICE mission - is not scheduled to arrive at Jupiter until 2030, while there are no plans in advanced development to send another vehicle to Saturn. It's a situation that Dr Spilker regrets, especially with regards to encouraging younger generations to become involved in what is no doubt one of the most interesting and important areas of space exploration.

"The lack of an outer planet mission until JUICE's arrival in 2030 is very unfortunate for planetary science," said Dr Spilker. "In particular, the current young generation of outer planet scientists will not have any new data after Cassini and JUNO [NASA's Jupiter orbiter, which is due to arrive on a one-year mission in 2016]."

Whatever does, eventually, come after Cassini will have an extremely hard act to follow. 15 years and counting, no spacecraft has increased our understanding of the Solar System, particularly Saturn and its surrounding system, like Cassini has, and it still has five more years to blow our minds again with new discoveries and observations. While we've taken a look here at the highlights of its groundbreaking mission so far, its continuing work will help us unearth many more secrets of the Solar System and beyond. ●

On its journey to Saturn, Cassini required a number of GAMs (gravity assist manoeuvres) and flybys

A journey of discovery

1. 26 April 1998: Manoeuvres
Cassini's first flyby was of Venus in April 1998, and it performed a second one on 24 June 1999. It flew by Earth on 18 August 1999, taking calibration photos of the Moon in the process.

2. 30 December 2000: Jupiter flyby
Cassini's flyby of Jupiter lasted several months, during which it took about 26,000 images and made extensive studies of the planet.

3. 2004: New moons
As Cassini approached Saturn in 2004 it began to discover a number of new moons. These included two within Saturn's ring system: Daphnis and Pan.

4. 1 July 2004: Saturn orbit
After a series of complex manoeuvres, it was confirmed that Cassini had entered orbit around Saturn, the first spacecraft ever to do so.

5. 2 July 2004: Titan flyby
Cassini made its first flyby of Saturn's largest moon, Titan. On 25 December it released the Huygens probe, which landed on Titan in 2005.

6. 2005: Enceladus flyby
In 2005, Cassini performed two flybys of Saturn's moon Enceladus, and observed water ice geysers erupting from the south pole. This has been one of Cassini's major finds.

7. May 2005: Saturn's rings
Cassini measured the size of particles in Saturn's rings by positioning the rings between itself and Earth and transmitting radio signals through them.

8. 21 July 2006: Lakes of Titan
Radar images revealed what seemed to be lakes of liquid methane and ethane on Titan, the first time surface liquids had ever been found off Earth.

9. November 2006: Saturn hurricane
A storm 8,000km (5,000 miles) across was found by Cassini at Saturn's south pole, with winds approaching 560km/h (350mph).

10. 10 September 2007: Iapetus flyby
Flying just 1,600km (1,000 miles) above its surface, Cassini imaged the strange two-toned moon of Iapetus and its giant equatorial ridge.

11. 2008: Equinox mission
Cassini's mission was extended, named the Cassini Equinox Mission, and it began by observing the ejected plumes of cryovolcanoes on Enceladus.

12. 2010: Solstice mission
Cassini's mission was again extended, this time named the Cassini Solstice Mission, until 2017. In late-2010, it observed Enceladus once more.

13. January 2011: Rhea flyby
Cassini flew within just 69km (43 miles) of the icy surface of Saturn's second-largest moon, Rhea.

14. 2012-2015: Titan observations
Cassini will observe Titan for about four years, performing multiple flybys and imaging its surface in great detail, as well as observing other moons.

15. 2015-2016: Enceladus and Titan
In 2015, Cassini will perform flybys of Enceladus, Epimetheus, Prometheus (right in image, next to Mimas) and Aegaeon before returning to Titan.

16. 2017: Saturn impact
It has been decided to end the Cassini mission in 2017. To prevent it crashing on a nearby moon, it will be sent to burn up in Saturn's atmosphere.

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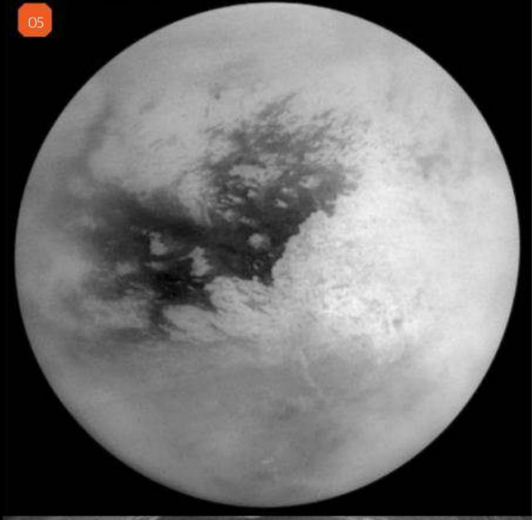
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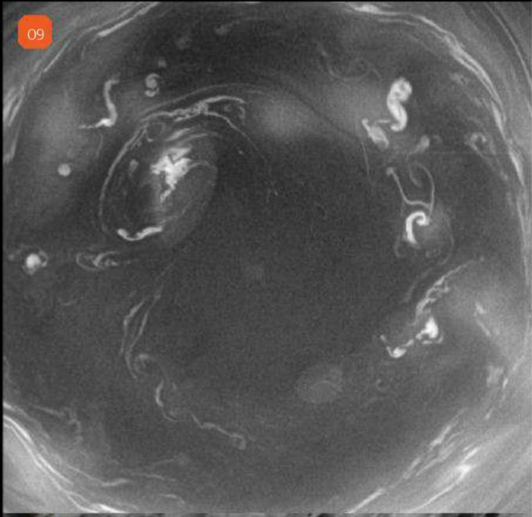
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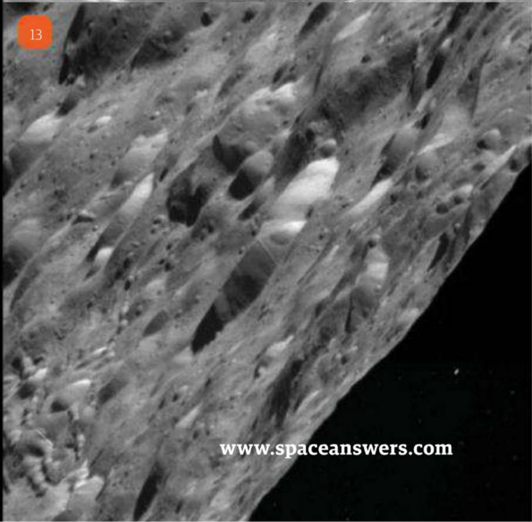
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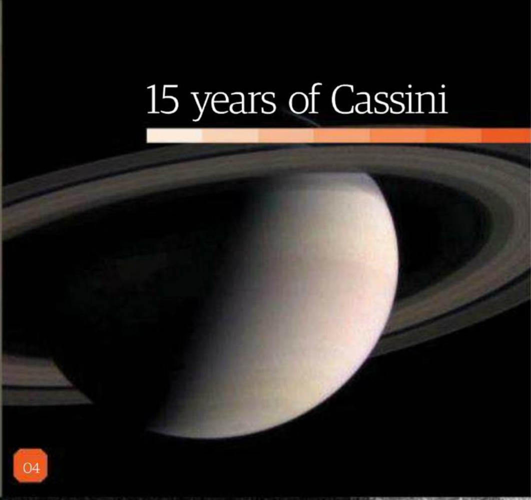
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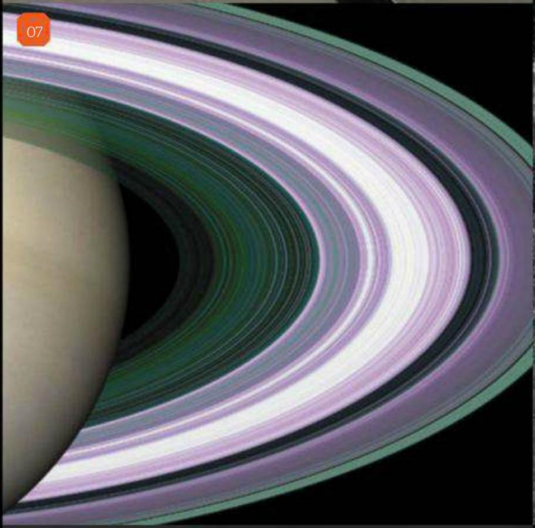
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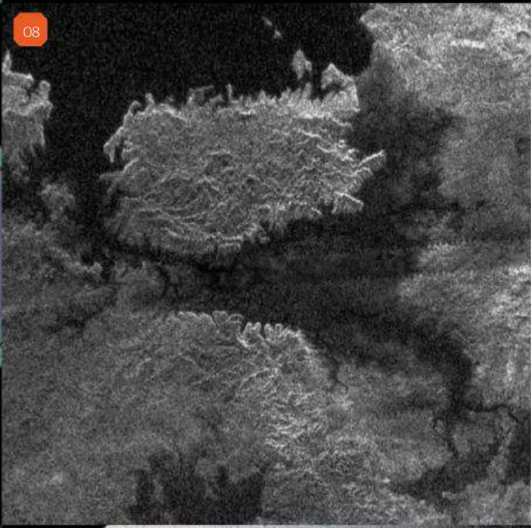
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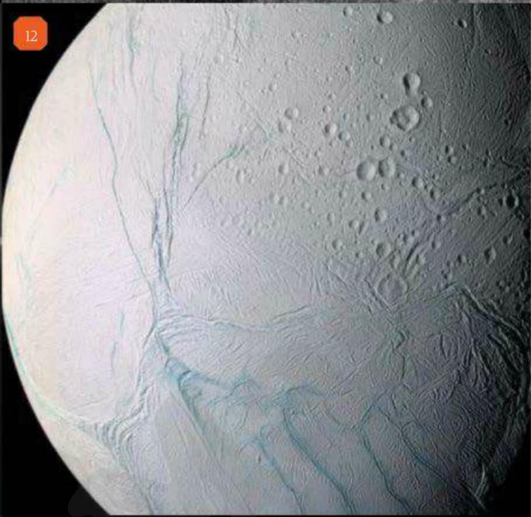
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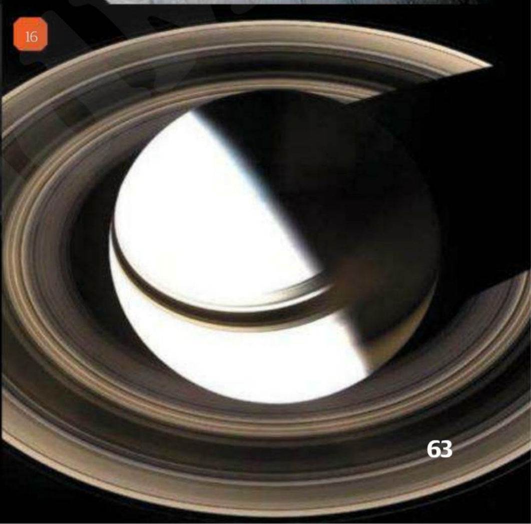
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The Huygens probe

Supplied by the European Space Agency (ESA), the Huygens probe provided us with our first chance to land on the surface of a world other than Venus, the Moon and Mars. It was an ambitious feat, aiming to traverse the somewhat unknown atmosphere of Titan before landing on the surface, be it water or solid rock. The probe could have landed on either, as little was known of this moon's surface.

The Huygens probe was attached to the Cassini orbiter for the majority of its seven-year trip to Saturn, during which it was dormant. Then, on Christmas Day 2004, the probe was released and sent on a collision course with Titan. It did not have its own propellant, so it was merely flung towards the moon by Cassini.

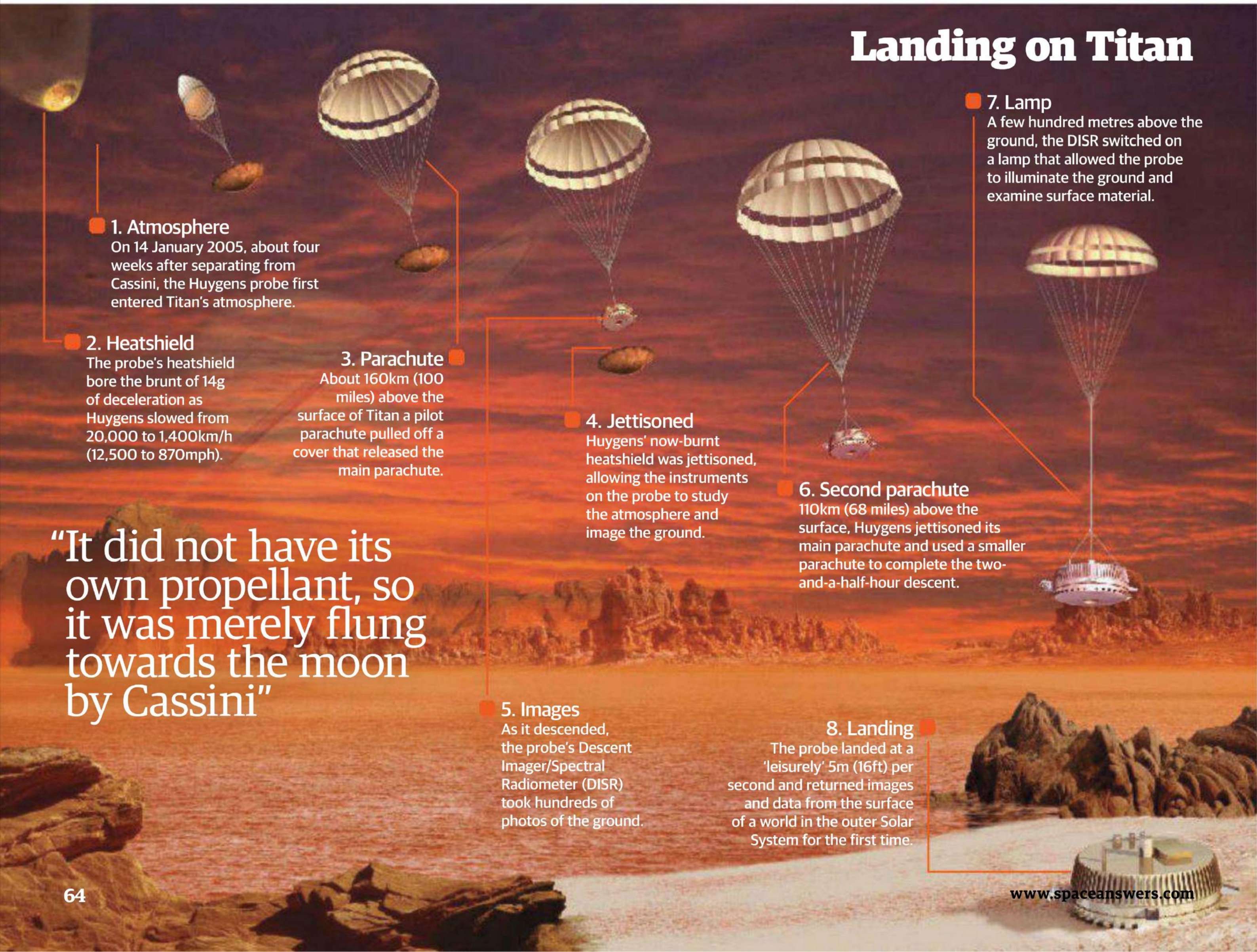
As the probe approached Titan, Cassini took images of its expected landing site and revealed that Huygens would be landing on what appeared to be a shoreline between rock and a possible liquid methane lake. The probe contained a number of scientific instruments including atmospheric sensors and a camera.

The probe used Cassini, at the time in the vicinity of Titan, as a relay between itself and Earth. Unfortunately, an operational commanding error meant that half of Huygens' data, including 350 images, were lost. However, from its descent it still managed to return incredible images of its journey all the way to the surface, which turned out to be partially solid rock similar in consistency to crème brûlée.

Huygens was a milestone in space exploration, one that has not and will not be repeated for many years.

Taken by Cassini, this image shows Titan's atmosphere

Landing on Titan



1. Atmosphere
On 14 January 2005, about four weeks after separating from Cassini, the Huygens probe first entered Titan's atmosphere.

2. Heatshield
The probe's heatshield bore the brunt of 14g of deceleration as Huygens slowed from 20,000 to 1,400km/h (12,500 to 870mph).

3. Parachute
About 160km (100 miles) above the surface of Titan a pilot parachute pulled off a cover that released the main parachute.

4. Jettisoned
Huygens' now-burnt heatshield was jettisoned, allowing the instruments on the probe to study the atmosphere and image the ground.

5. Images
As it descended, the probe's Descent Imager/Spectral Radiometer (DISR) took hundreds of photos of the ground.

6. Second parachute
110km (68 miles) above the surface, Huygens jettisoned its main parachute and used a smaller parachute to complete the two-and-a-half-hour descent.

7. Lamp
A few hundred metres above the ground, the DISR switched on a lamp that allowed the probe to illuminate the ground and examine surface material.

8. Landing
The probe landed at a 'leisurely' 5m (16ft) per second and returned images and data from the surface of a world in the outer Solar System for the first time.

> "It did not have its own propellant, so it was merely flung towards the moon by Cassini"

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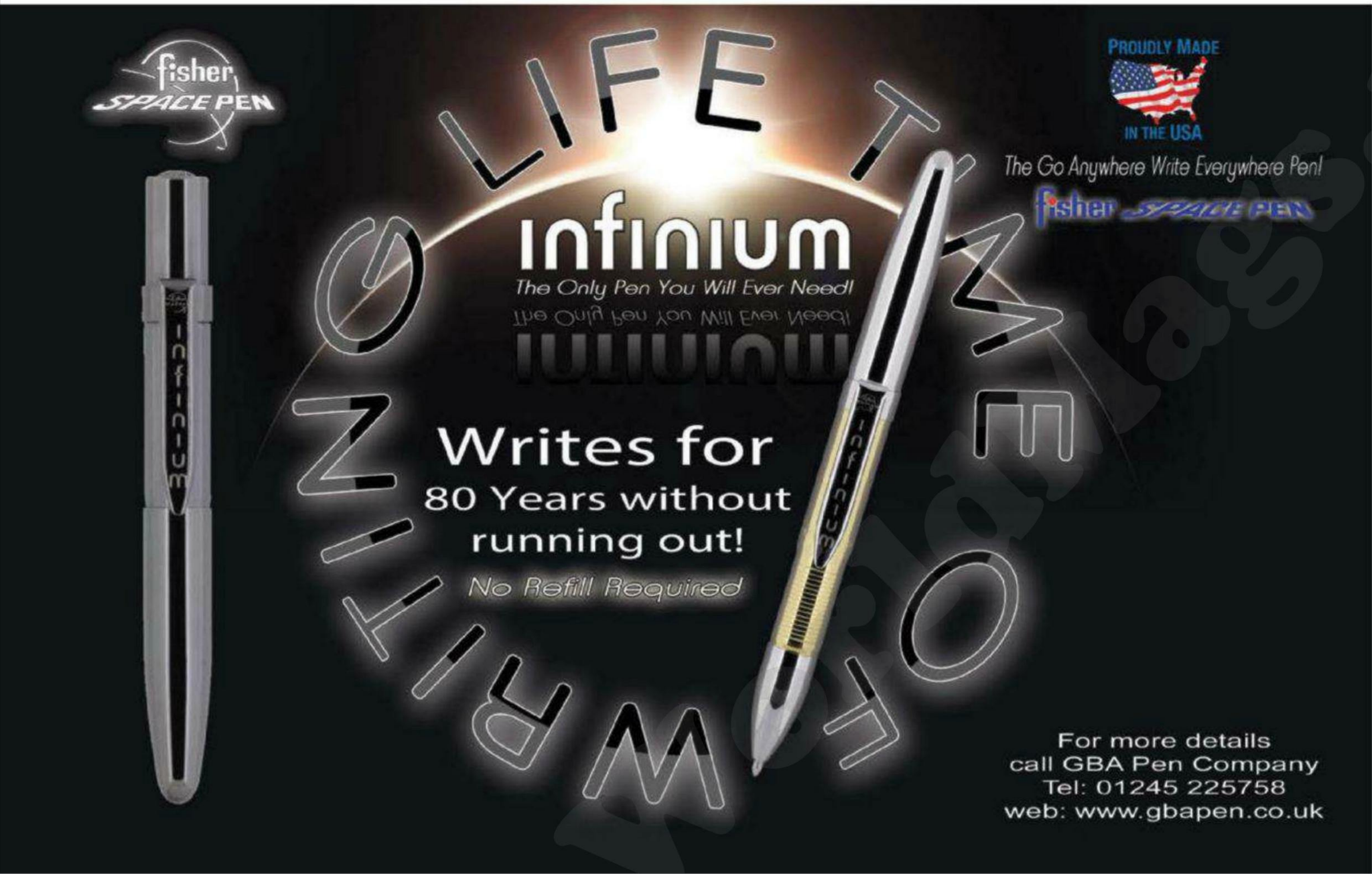

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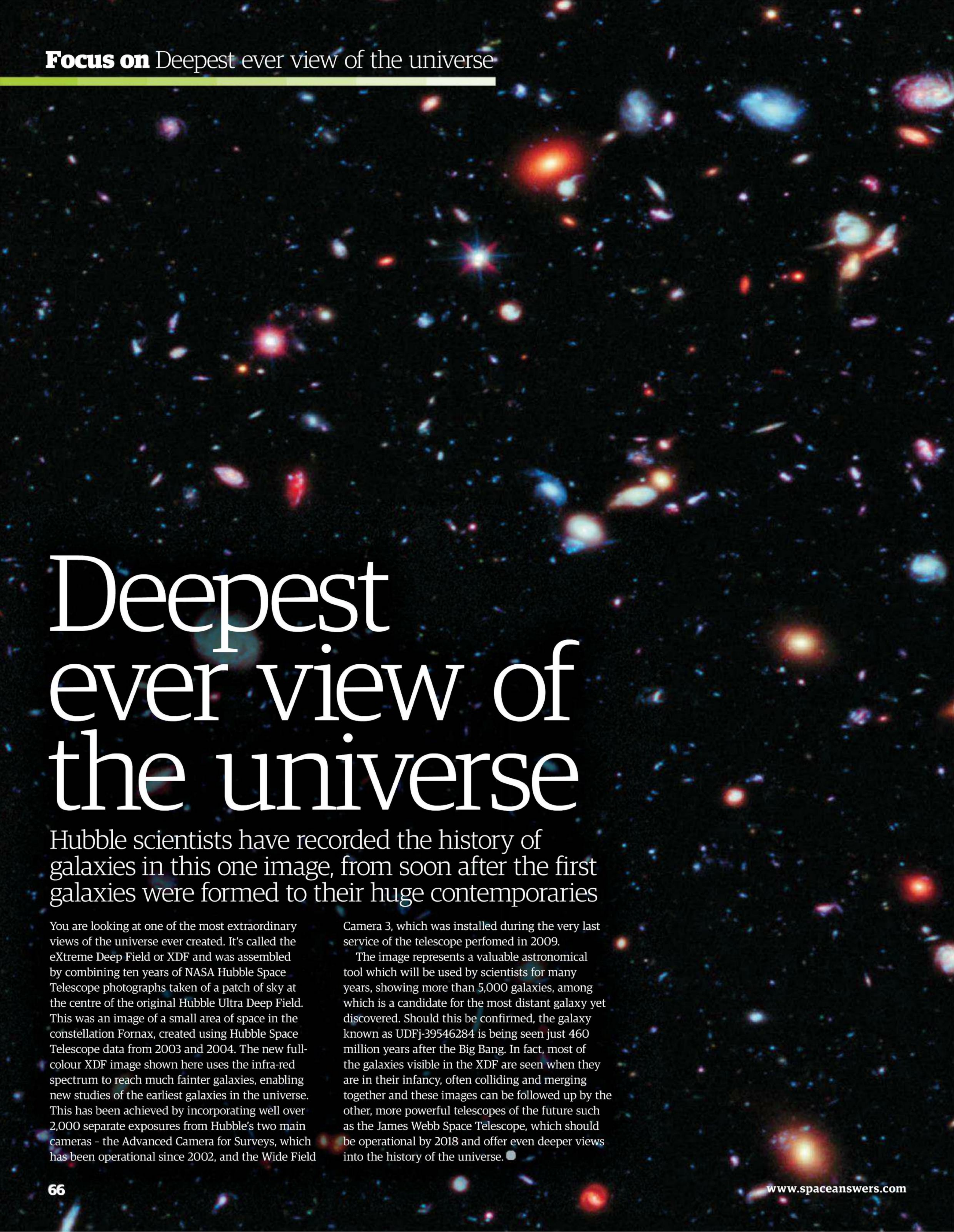


Deepest ever view of the universe

Hubble scientists have recorded the history of galaxies in this one image, from soon after the first galaxies were formed to their huge contemporaries

You are looking at one of the most extraordinary views of the universe ever created. It's called the eXtreme Deep Field or XDF and was assembled by combining ten years of NASA Hubble Space Telescope photographs taken of a patch of sky at the centre of the original Hubble Ultra Deep Field. This was an image of a small area of space in the constellation Fornax, created using Hubble Space Telescope data from 2003 and 2004. The new full-colour XDF image shown here uses the infra-red spectrum to reach much fainter galaxies, enabling new studies of the earliest galaxies in the universe. This has been achieved by incorporating well over 2,000 separate exposures from Hubble's two main cameras – the Advanced Camera for Surveys, which has been operational since 2002, and the Wide Field Camera 3, which was installed during the very last service of the telescope perfomed in 2009.

The image represents a valuable astronomical tool which will be used by scientists for many years, showing more than 5,000 galaxies, among which is a candidate for the most distant galaxy yet discovered. Should this be confirmed, the galaxy known as UDFj-39546284 is being seen just 460 million years after the Big Bang. In fact, most of the galaxies visible in the XDF are seen when they are in their infancy, often colliding and merging together and these images can be followed up by the other, more powerful telescopes of the future such as the James Webb Space Telescope, which should be operational by 2018 and offer even deeper views into the history of the universe.

This image was created from over 2,000 separate exposures captured by the Hubble Space Telescope

WorldMags

The story of Skylab

Written by Jonathan O'Callaghan

NASA's first space station provided the groundwork for prolonged space habitation before its untimely demise

In 1971, the Soviet Union launched the world's first space station, Salyut 1, to global acclaim. Not one to be outdone by the USSR, NASA already had plans in the works for a bigger and better example that would lay the groundwork for future space stations, including Mir and the ISS. Enter Skylab, NASA's pioneering space settlement of the Seventies.

During the Fifties, rocket scientist Wernher von Braun, alongside other space visionaries, outlined his plan to build a giant rotating space habitat that would house many people in orbit. The proposal, although ambitious, was seriously considered by NASA and other agencies as a means to explore beyond Earth orbit, specifically the Moon. Following the creation of Project Apollo, however, which did not require in-orbit assembly, von Braun's ambitious plans were scrapped.

NASA, however, still saw the benefits of launching a space station, especially for scientific purposes and to ascertain the ability of humans to operate for a prolonged period in space. Therefore, in 1963, NASA and the Department of Defense (DoD) decided to co-operate in the building of a space station, although their objectives proved to be different and NASA decided to go ahead with construction of Skylab alone.

Skylab was launched atop a modified Saturn V rocket on 14 May 1973, the last time this iconic rocket ever launched. The modifications were the upper stage of the rocket. Skylab was basically a refurbished third stage of a rocket gutted out and made into an orbital workshop, which was placed inside the upper stage of the Saturn V rocket. Astronauts launched to the station in an Apollo Command and Service Module atop a smaller Saturn 1B rocket. Unlike the ISS, which took over 12 years to build, Skylab was built in its entirety and required only one unmanned launch.

Less than two weeks later, on 25 May 1973, the first three-manned crew (Charles 'Pete' Conrad, Paul Weitz and Joseph Kerwin) launched to the station. However, their arrival was not devoid of problems. During the unmanned launch of Skylab a micrometeoroid shield had torn off the station. Not only did this rip off one of the solar panels and prevent the other from deploying, but it also left the station with no defence against incoming solar radiation. This raised the temperature on Skylab to 52 degrees Celsius (126 degrees Fahrenheit). When the first crew arrived, their first task was to deploy a makeshift parasol with a spacewalk to lower the temperature and deploy the stuck solar panel, bringing the station up to near full power.

With the problems overcome, Skylab was ready to fulfil its promise. One of the most important tasks of the Skylab missions was to see how humans coped with prolonged stays in space. The three astronauts performed daily biological tests, taking turns to act as the 'guinea pig' as the others monitored their bodies. These ranged from basic physical exercises to blood tests and other medical examinations. The astronauts' days lasted from 6am to 10pm (Houston time), during which they each conducted solar observations and other experiments. The crew also had a number of experiments designed by students to carry out, which were generally a bit more light-hearted than those arranged by NASA. These included observing the motion of a blob of water in zero-gravity and playing catch to test hand-eye co-ordination.

> "Skylab moved into a state of freefall and, on 11 July 1979, it began to re-enter the Earth's atmosphere"

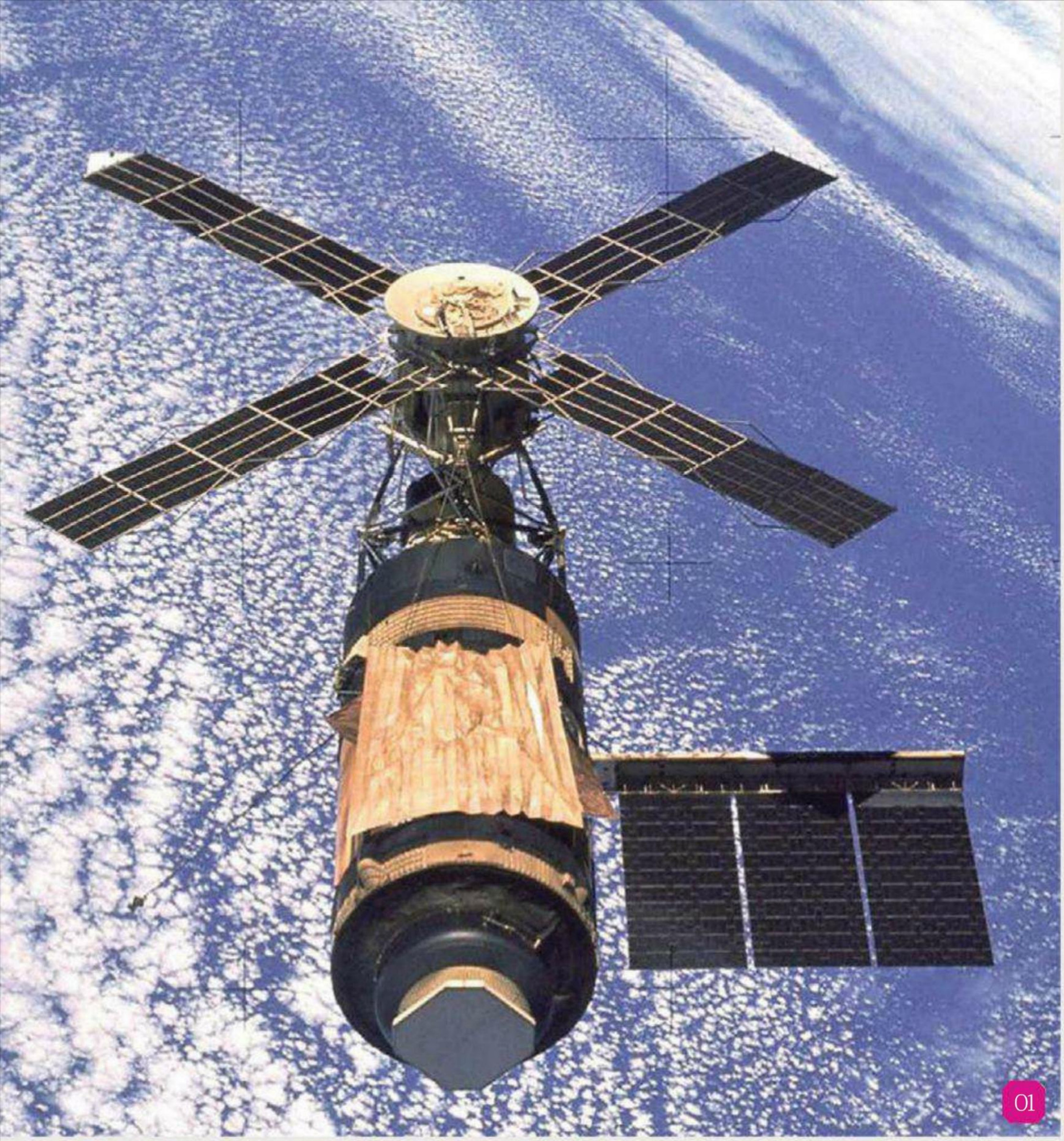
Skylab 3 astronaut Owen Garriott performs a spacewalk

Skylab was a surprisingly large station, comparable in liveable space to a three-bedroom house. It had a number of amenities that were tested for the first time and would become mainstays of future space stations Mir and the International Space Station, including a toilet and shower. After overcoming the initial disorientation of living in zero-gravity, all nine astronauts who stayed on Skylab reported no problems operating in a weightless environment. All their experiments were highly successful and, using the solar observatory attached to the station (the Apollo Telescope Mount), the astronauts performed the most detailed observations of the Sun at the time.

In total three different three-man crews visited the station, Skylab 2, 3 and 4, with the trips lasting 28, 59 and 84 days respectively. The last mission to the station departed on 8 February 1974. In anticipation of another crew visiting the station following their exit, the astronauts left behind supplies including food and water. The events that followed, however, meant that astronauts Gerald Carr, William Pogue and Edward Gibson would be the last residents on Skylab.

The original plan was for Skylab to remain in orbit for another ten or so years, with crews possibly being brought to the station by the Space Shuttle. However, in 1978 it was discovered that the Sun was entering a period of increased solar activity, which in turn would push Skylab lower in its orbit, culminating in an uncontrolled re-entry in 1979. NASA devised a plan to use a Space Shuttle to boost the station higher but, when the Space Shuttle programme was delayed until 1982, it became apparent that Skylab could not be saved.

The size of Skylab meant that it wouldn't entirely burn up in the



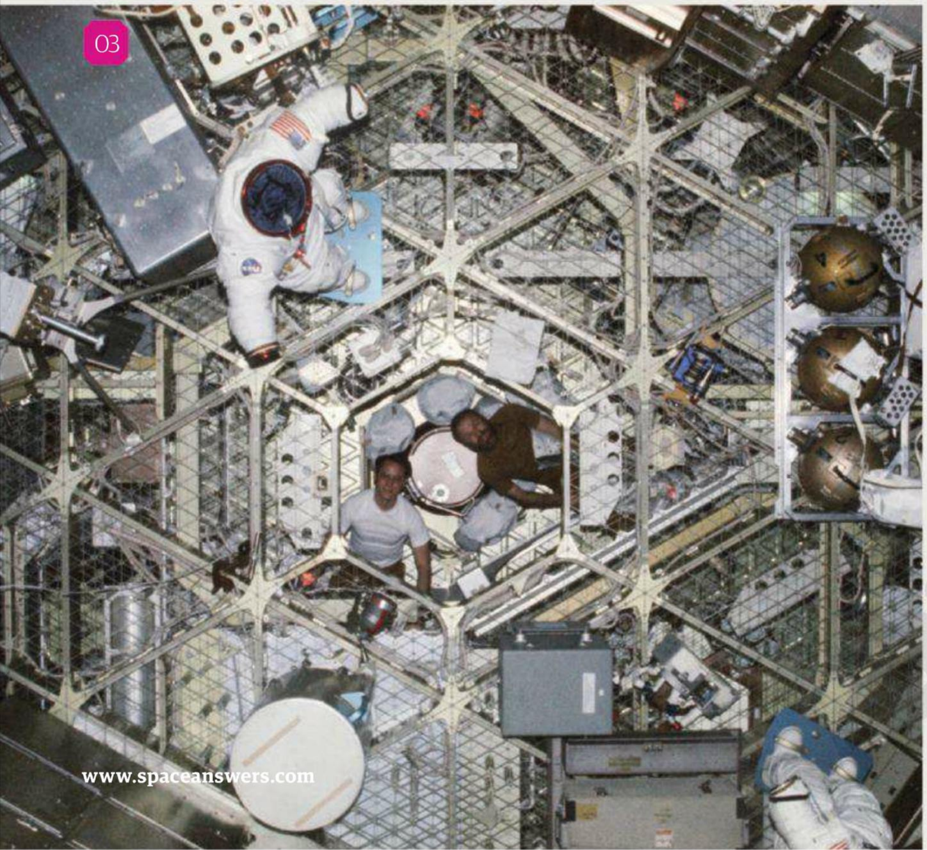
1. Skylab
Only one of Skylab's two solar panels managed to deploy successfully after launch.

2. Launch
Skylab launched on a modified Saturn V rocket in 1973.

3. Spacious
The interior of Skylab was surprisingly large.

4. Zero-gravity
Two Skylab astronauts demonstrate zero-gravity.

5. Food
Meals on Skylab were a step-up from previous space missions.



atmosphere, and it was likely that debris would make it to the surface. In addition, ground control did not have complete control over the station, so they could not direct where the debris would land. Skylab moved into a state of freefall and, on 11 July 1979, it began to re-enter the atmosphere amid a media maelstrom.

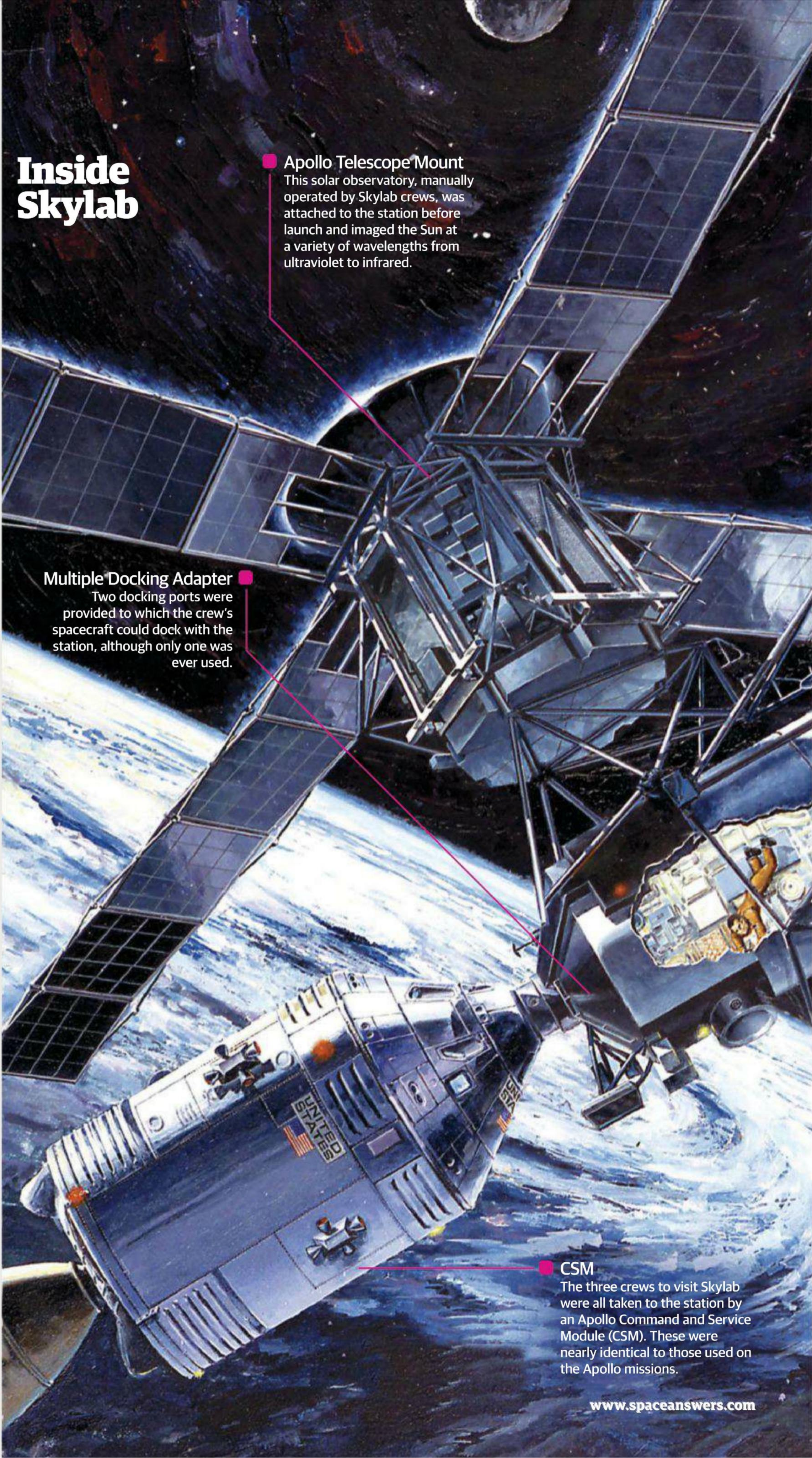
As it descended the station burned up and broke apart, but parts of it managed to survive the harsh temperatures of re-entry. Initial reports said that it had fallen safely into the Indian Ocean away from populated areas. One community in Western Australia, however, disagreed. Residents in the Shire of Esperance were startled when a multitude of sonic booms could suddenly be heard in the sky as pieces of debris broke the sound barrier. Chunks of Skylab rained across Esperance, including an oxygen tank, but fortunately no one was harmed.

Esperance took it all on the chin, however, and there were several endearing stories to come out of the incident. Stan Thornton, a 17-year-old from the area, was alerted by his mother to a piece of Skylab debris in the family's garden. After learning that the *San Francisco Examiner* was offering $10,000 USD to anyone who could deliver a piece of Skylab debris to its office, Stan cooled down the debris, hopped on a plane to San Francisco with nothing more than a toothbrush and his wallet and was greeted by throngs of media who watched him claim his prize.

Esperance also jokingly fined NASA $400 for 'littering'. Despite several requests from the American public to pay it over the years, the fee remained unpaid until a persistent radio host arrived in Esperance in 2009 with a cheque for the full amount of money, donated by his listeners. Scott Barley of the Highway Radio in Barstow, California handed over the money to widespread applause as people remembered the event that put the Shire of Esperance firmly on the map.

Skylab's high-profile demise was testament to its massive significance in an age where space exploration was still riding the waves of the previous Apollo successes. It will forever be regarded as one of NASA's pioneering achievements that certainly paved the way for the current International Space Station, providing a large amount of key information and experimental evidence that will doubtless prove useful for future missions in decades to come.

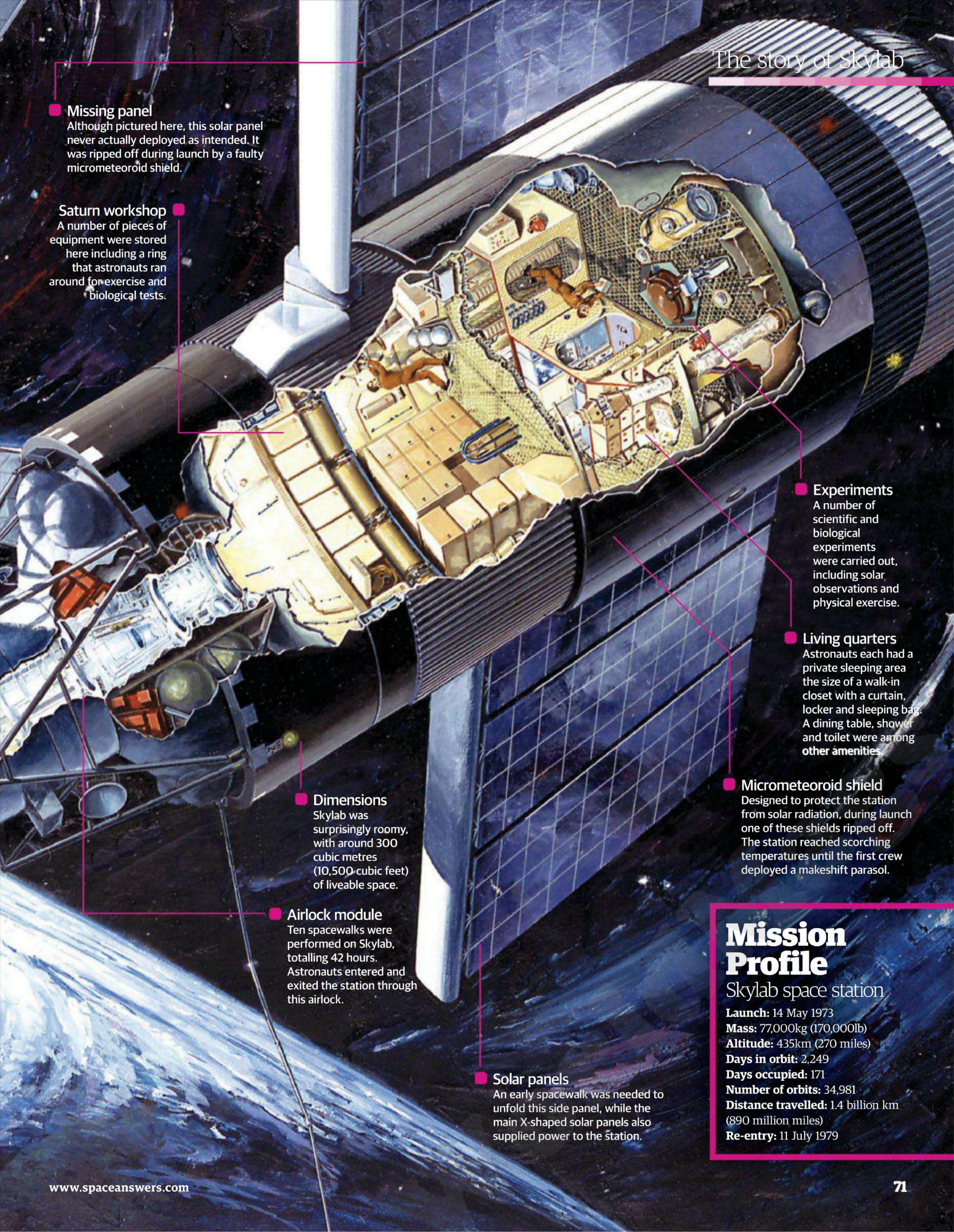
Inside Skylab



Apollo Telescope Mount
This solar observatory, manually operated by Skylab crews, was attached to the station before launch and imaged the Sun at a variety of wavelengths from ultraviolet to infrared.

Multiple Docking Adapter
Two docking ports were provided to which the crew's spacecraft could dock with the station, although only one was ever used.

CSM
The three crews to visit Skylab were all taken to the station by an Apollo Command and Service Module (CSM). These were nearly identical to those used on the Apollo missions.



Missing panel
Although pictured here, this solar panel never actually deployed as intended. It was ripped off during launch by a faulty micrometeoroid shield.

Saturn workshop
A number of pieces of equipment were stored here including a ring that astronauts ran around for exercise and biological tests.

Experiments
A number of scientific and biological experiments were carried out, including solar observations and physical exercise.

Living quarters
Astronauts each had a private sleeping area the size of a walk-in closet with a curtain, locker and sleeping bag. A dining table, shower and toilet were among other amenities.

Micrometeoroid shield
Designed to protect the station from solar radiation, during launch one of these shields ripped off. The station reached scorching temperatures until the first crew deployed a makeshift parasol.

Dimensions
Skylab was surprisingly roomy, with around 300 cubic metres (10,500 cubic feet) of liveable space.

Airlock module
Ten spacewalks were performed on Skylab, totalling 42 hours. Astronauts entered and exited the station through this airlock.

Solar panels
An early spacewalk was needed to unfold this side panel, while the main X-shaped solar panels also supplied power to the station.

Mission Profile

Skylab space station

Launch: 14 May 1973
Mass: 77,000kg (170,000lb)
Altitude: 435km (270 miles)
Days in orbit: 2,249
Days occupied: 171
Number of orbits: 34,981
Distance travelled: 1.4 billion km (890 million miles)
Re-entry: 11 July 1979

Comet harpoon

Could we fire a capsule into a comet to return samples to Earth?

In issue 3 we looked at how tractor beams might be used to transport particles from a celestial body to a spacecraft. Elsewhere, scientists at NASA's Goddard Space Flight Center have been looking at something just as innovative to return a sample from a comet - a harpoon-wielding spacecraft.

If you're imagining a boat's harpoon gun in space, then you're not far off. This remarkable concept would place a spacecraft in the vicinity of a comet before firing a sample capsule, attached to the spacecraft with a tether, into the comet. It would retrieve a sample before winching it back to the spacecraft and flying back to Earth.

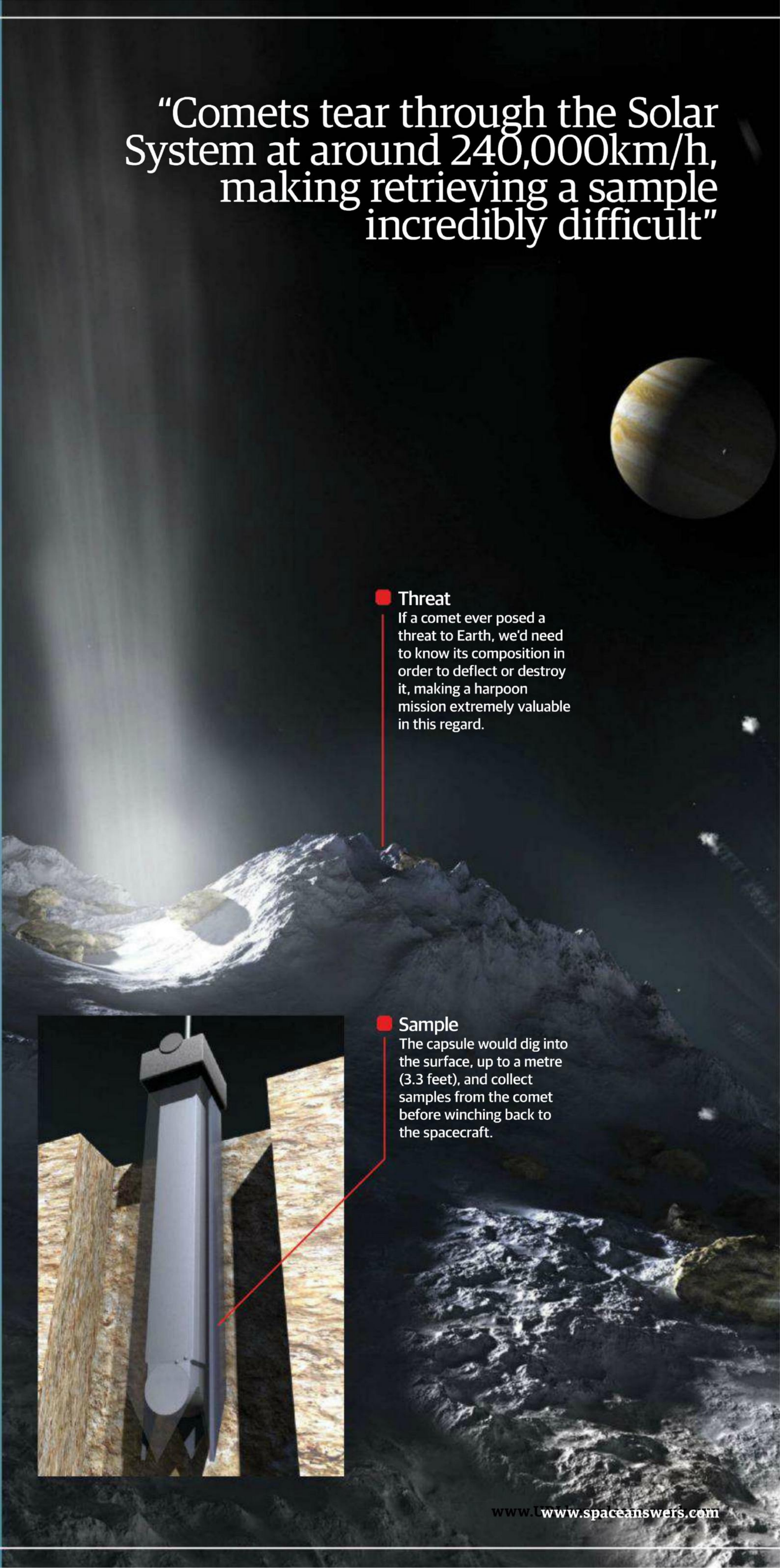
The testing so far has seen scientists develop a large crossbow 1.8 metres (six feet) tall to fire a projectile into a mock comet with a force of around 450 kilograms (1,000 pounds) at 30 metres (100 feet) per second. A similar device could be attached to a spacecraft and sent to space where it would use explosive powder to fire a capsule into a comet and winch a sample back.

The desire to research the comet harpoon method came about after scientists discussed how best to return a sample from icy and mineral-rich comets, which are of great interest as they may have carried the building blocks of life in the early Solar System. Landing on a comet has been mooted for some time, although no nation has yet accomplished it.

Some comets tear through the Solar System at up to 240,000 kilometres per hour (150,000 miles per hour), making retrieving a sample incredibly difficult. NASA's new comet harpoon mission offers several benefits over a landing mission. "The harpoon mission does not need to land, so it can sample from virtually any terrain," said lead scientist on the project Dr Joseph Nuth. "A harpoon obtains a sample very quickly, in less than a minute, rather than over days or weeks for a drill on a lander."

A harpoon could bring back samples up to a metre (3.3 feet) beneath a comet's surface, which would "be a collection of dust and volatiles that should contain a representative sample of the materials making up the comet," said Dr Nuth. This in turn could provide useful data on the formation of the solar nebula.

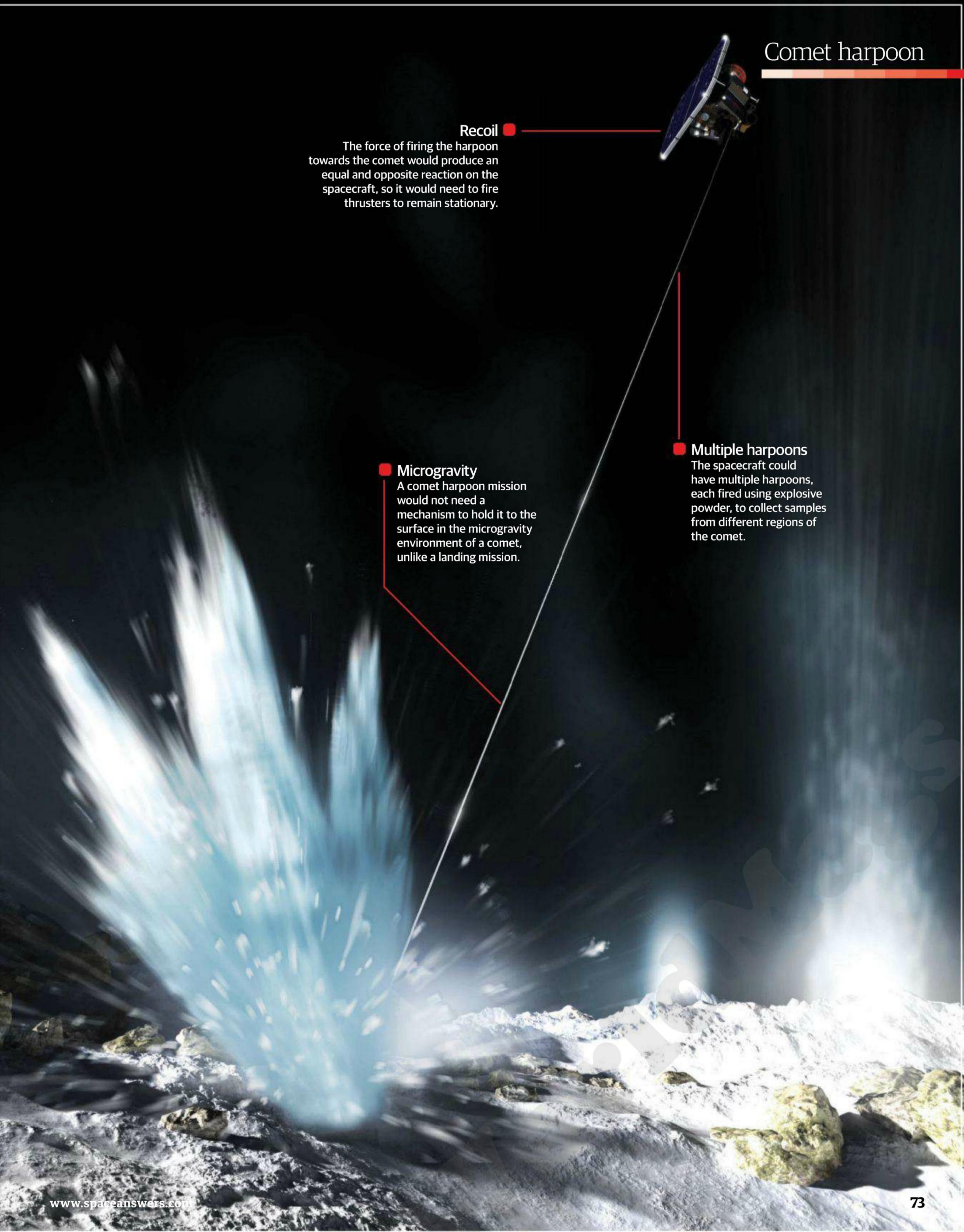
So, when can we expect to see such a mission? "The next New Frontiers opportunity will not be until at least 2016," said Dr Nuth. "The time to build and launch a mission of this complexity is four to five years and the cruise time is also on the order of five to seven years. Sample return could take another three to five years. This means that the sample would return sometime in the 2030s."



"Comets tear through the Solar System at around 240,000km/h, making retrieving a sample incredibly difficult"

Threat
If a comet ever posed a threat to Earth, we'd need to know its composition in order to deflect or destroy it, making a harpoon mission extremely valuable in this regard.

Sample
The capsule would dig into the surface, up to a metre (3.3 feet), and collect samples from the comet before winching back to the spacecraft.



Recoil
The force of firing the harpoon towards the comet would produce an equal and opposite reaction on the spacecraft, so it would need to fire thrusters to remain stationary.

Multiple harpoons
The spacecraft could have multiple harpoons, each fired using explosive powder, to collect samples from different regions of the comet.

Microgravity
A comet harpoon mission would not need a mechanism to hold it to the surface in the microgravity environment of a comet, unlike a landing mission.

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…of a crater or planet's polar regions, ice has been spotted by spacecraft all over the Solar System.

Like a bad poker player, ice has several 'tells' that inform scientists of its presence. Satellites swooping over a suspected icy area are on the hunt for patches of unusual brightness, or 'spectrums' of elements that include

pole's Shackleton Crater and found what is believed to be water ice.

The LRO also has a radar instrument on board, which scanned the sides of the crater during another orbit of the Moon. Various types of terrain show up differently on radar; for example, a flat surface appears black because all of the radar pulses hit at the same height. The 'signature'

ice. It's likely laced with ammonia - which on Earth is an industrial poison. It also contains methane, which in gas form contributes to the greenhouse effect on Earth. Titan's a bit of a weird moon. It sits about 1.4 billion kilometres (870 million miles) from the Sun - around ten times farther away than Earth. The Sun is but a bright star in the sky.

a long time ago - unless there was some kind of an internal source that regenerates the methane.

Most of Titan is covered with water ice, but scientists suspect there's a big watery ocean underneath. In 2010, Cassini scientists released a study proposing that ocean might have ammonia 'salting' the liquid. The water-ammonia slush, if it rubbed

Earth. NASA smashed a spacecraft into Comet Tempel 1 in 2005. The appropriately named Deep Impact uncovered a few interesting things.

Just beneath the surface of the comet is both water ice and 'dry' (carbon dioxide) ice. When the comet gets close to the Sun, the dry ice melts first. But if it's buried underneath more water ice - as is the case on

was entirely made up of regolith, or Moon dirt. But some were curious about the deepest craters on our satellite. Could ice lurk there, protected from the rays of the Sun? NASA seems to think the answer is yes, after examining data from several spacecraft. In 2009, the agency threw the ageing Lunar Crater Observation and Sensing Satellite (LCROSS) at

Frozen worlds of the Solar System

The Moon
Protected from the Sun, the deepest, darkest craters at the Moon's poles are believed to almost certainly contain traces of water ice.

Europa
Europa's bright, fractured surface is a likely sign of water ice. Scientists believe Europa has an icy crust of a few kilometres thick, with an ocean underneath.

Ganymede
Ganymede's ice shell is about 800km (500 miles) thick, according to NASA. The lumpy ice on Ganymede's surface probably has some rock mixed in too.

Callisto
The ice on Callisto's surface occasionally twists into 100m (330ft)-tall spires. NASA believes these are the leftovers of material thrown out during a large meteor impact millions of years ago.

Titan
Titan's ice, which covers much of the Saturnian moon, is a combination of water and methane. Scientists believe a water-ammonia ocean lurks beneath the surface.

Enceladus
The gravity of Saturn warps the ice on Enceladus, causing deep cracks and geysers. The spacecraft Cassini found these cracks become more strained as Enceladus gets closer to Saturn in its orbit.

Triton
At 4.5 billion km (2.8 billion miles) from the Sun, Triton is so cold that nitrogen freezes on its surface. It's the only moon that we know of to have a surface mainly composed of nitrogen ice.

Umbriel
The Voyager spacecraft found evidence of water ice on Umbriel in the Eighties, after measuring its spectrum.

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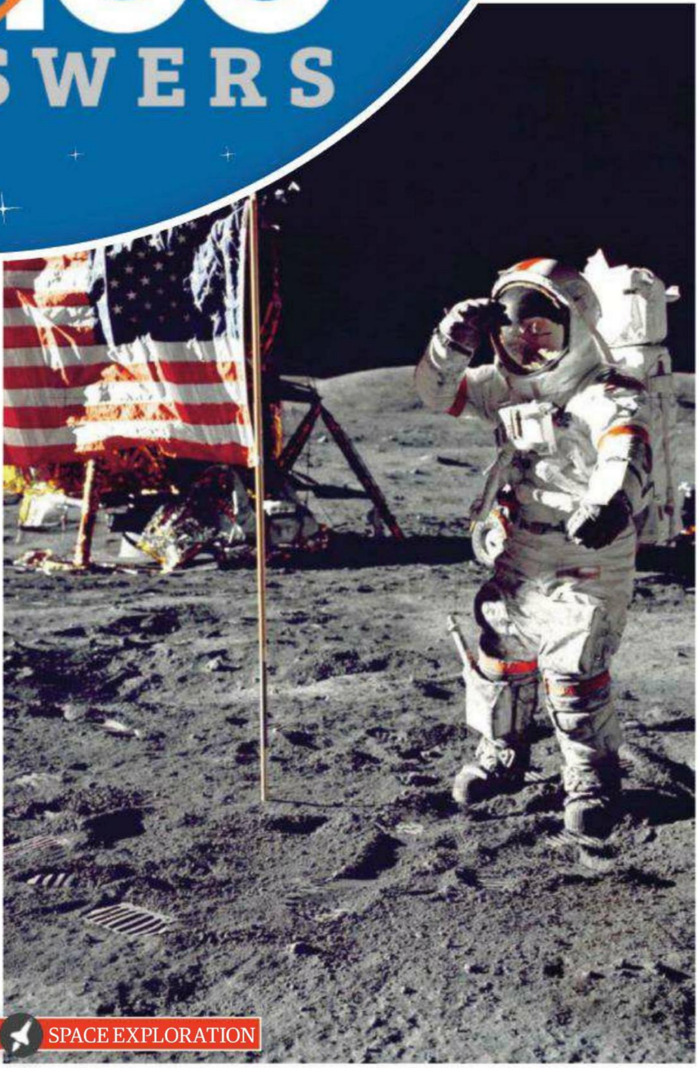

SPACE EXPLORATION

Does the US own the Moon?

Conrad Tibbs

'Finders, keepers' has often been used in Earth-based exploration. The first person into a new territory often lays claim to it for himself or on behalf of a country. Methods like this have often been considered when discussing the Moon and other objects in our Solar System. These questions have become even more relevant with people looking at the possibility of harvesting the Moon or asteroids for resources.

Luckily these outcomes have been considered. Back in 1967 the 'Outer Space Treaty' was written and to date over 100 countries have signed it. This treaty looks to provide a simple legal framework to use regarding the space around Earth and the rest of the Solar System. Under this 'Space law', claiming of any region of space or celestial body – Moon, asteroid etc – is expressly forbidden, as is the use of these objects for any military purposes. Countries are also asked to be responsible for their actions, ensuring nothing they do threatens the peaceful exploration and operation in space of others. **JB**

SPACE EXPLORATION

What is an escape velocity?

Owain Jones

Escape velocity is the speed required to break free and depart the gravitational pull of an object like the Earth or other celestial body without the need for further propulsion. Of course, that varies widely depending on the mass of a planet or moon for instance. To avoid being pulled back, the object must reach the minimum escape velocity. In 1959, the Luna 1 spacecraft built by the Soviet Union was the first man-made object to reach escape velocity and flew by the Moon two days later at a distance of about 6,000 kilometres. Luna 1 is still in solar orbit and has not escaped the gravitational influence of the Sun. To leave Earth requires a speed of about 25,000mph or 7 miles/sec (11.2km/sec). Whereas on our Moon, which is about a quarter the diameter of Earth, the escape velocity is only about 5,300mph or 2.38km/sec. By contrast, the escape velocity of our gigantic Sun is about 1,381,000mph or 618km/sec. **KK**

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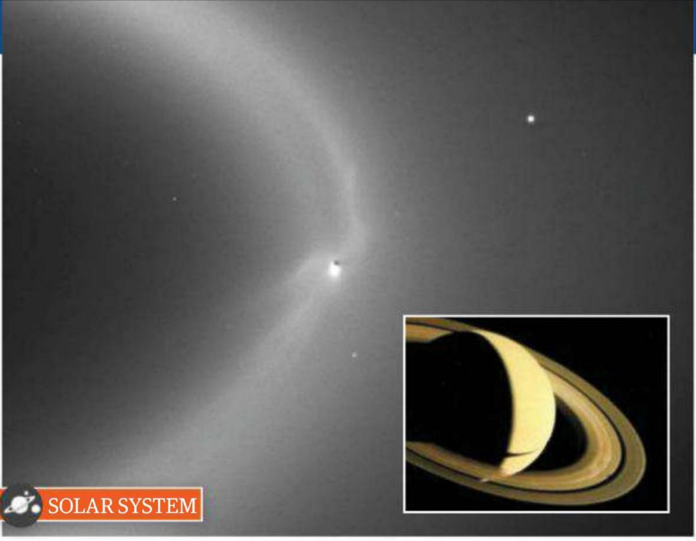


SOLAR SYSTEM

How did Saturn get its rings?

Adam Bennett

The question of Saturn's rings' formation has puzzled scientists ever since Huygens first described them as a disc in 1655. This was 45 years after Galileo compared them to ears around the planet. Although humanity's understanding of these ring structures has hugely increased since then, especially since the Cassini spacecraft arrived at the system in 2004, there are still different theories about the formation of these rings. The main differences are whether the rings formed at the same time as Saturn itself or whether they formed later, possibly after the collision of moons. To complicate matters further, it is possible that both ideas are correct but apply to different parts of the ring structure. For example, Cassini discovered in 2005 that the E Ring is continually replenished by ice volcanoes on the moon Enceladus spurting material out into space. It is only by investigating the rings further that a clearer theory of formation will be developed. **MW**

Auroras are fantastically beautiful light shows

ASTRONOMY

How far south are the auroras visible?

Richard West

The Southern Lights (aurora australis) are the counterpart of the Northern Lights (aurora borealis). This natural light display can be seen as far south as the tip of South America, Australia, New Zealand, Antarctica and the South Pole. Astronauts aboard the Space Shuttle and ISS have photographed the auroras from orbit too. They are less visible at the lower latitudes where most Earthlings reside. Auroras are caused when energetic, charged particles from the Sun collide with high-altitude atoms of oxygen and nitrogen in the atmosphere above both magnetic poles and accelerate along the lines of Earth's magnetic field. Auroras have been spotted on other planets like Jupiter and Saturn by unmanned space probes. **KK**

SOLAR SYSTEM

How many machines have landed on Mars?

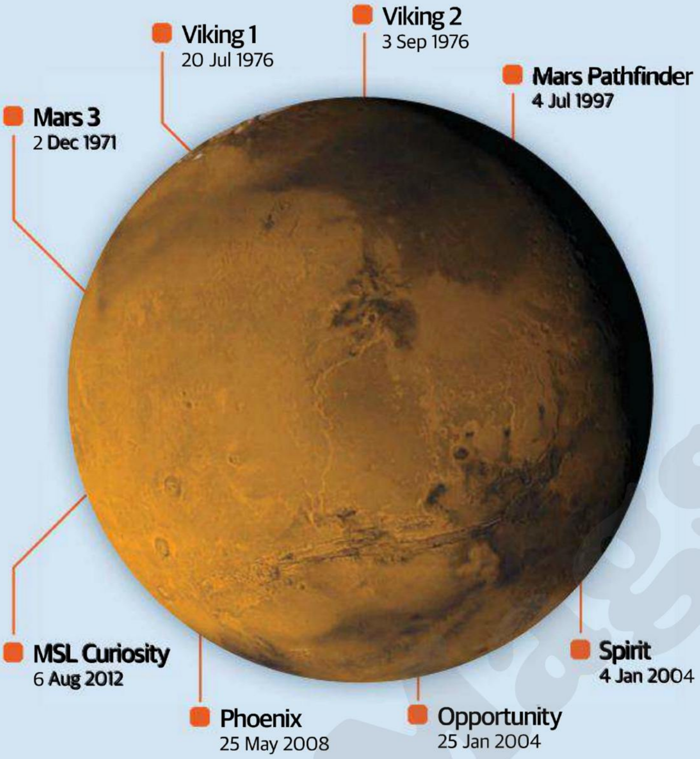
Beth Hutchins

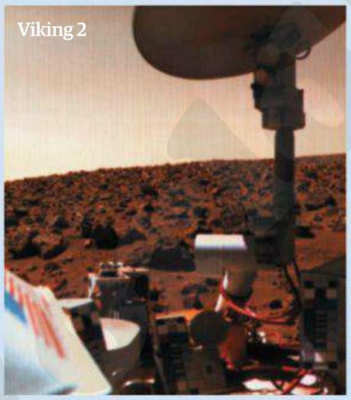
With the recent success of NASA MSL's Curiosity rover, interest in Mars runs high. However, it is easy to forget what a feat of engineering and ingenuity this was. Getting probes to Mars is notoriously difficult.

Over half of all Mars missions have been unsuccessful, with Russia (and the former Soviet Union) experiencing a particular Martian curse. In fact, with only one successful landing (where communications were lost after 15 seconds) and two fully successful orbiting craft, they lag behind the US considerably in this area.

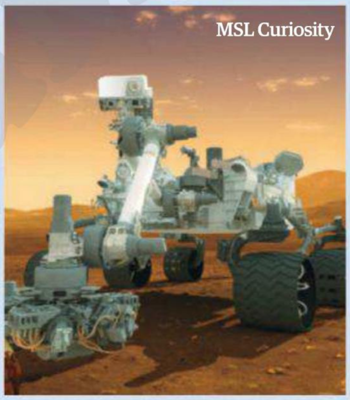
Despite these difficulties, eight craft have managed to land on the surface of the Red Planet, seven of those being US craft. A further five have crash-landed on the surface (including, sadly, Britain's own Beagle 2 lander).

However, the craft that have been successful have revolutionised our knowledge of our 'little red brother', and sometimes the most amazing achievements stem from the most difficult of tasks. **SA**





Viking 2



MSL Curiosity

DEEP SPACE

What is the minimum size a body can become a sphere?

Rab Manderson

For a body to become a sphere, it has to have sufficient self-gravity to pull it into a spherical shape. This depends on what the body is made of, for two reasons. The first reason is because the strength of self-gravity depends on the mass of the object rather than its size, implying that bodies made of denser materials become spherical at smaller radii. The second reason is that some materials are easier to mould into a sphere than others, implying that less strong gravity is needed to push some materials into a spherical shape. The second reason tends to win out. Therefore, for bodies made mainly of rock, the minimum size to become a self-gravitating sphere is about 600km diameter; but, for bodies mainly made of ice, the minimum size is about 400km diameter. **MW**

SPACE EXPLORATION

How do you join NASA?

Tyron Tsang

This depends on what you want to do there. For a technical/science role you'd need a degree in subjects like Aerospace, Aeronautical Engineering, Mechanical/Electrical Engineering, Materials Engineering, Cryogenics, Thermal Engineering, or any science that is integral to a specific mission.

Becoming an astronaut is different, as NASA wants candidates from specialised areas and the admission criteria are far stricter.

Also, only US citizens are eligible for all permanent roles within NASA. So you would need to obtain US citizenship (which several British scientists have done). **SA**

SPACE EXPLORATION

Do they 'make' oxygen to breathe on the ISS?

Hugh Banks

Electrolysis of water (H_2O) is the main method to generate oxygen aboard the ISS. Water is split into oxygen (O_2) and hydrogen (H_2). The oxygen is vented into the breathable cabin air system, known as the Oxygen Generation System, while the explosive hydrogen is vented externally. The station's football-field-sized solar arrays are the power source to electrolyse the water. Each day the OGS continuously provides between 2.3 and 9kg (5 to 20lbs) of oxygen. The OGS is a component of the ISS life support system, known as ECLSS or Environmental Control and Life Support System, located in the US Destiny module. The Elektron system aboard the Russian Zvezda service module performs the same vital electrolysis service for the ISS crew. The Electron system was also used aboard the Russian Mir Space Station. Pressurised oxygen storage tanks replenished by visiting unmanned cargo ships provide a backup to the electrolysis method. Finally, the crew can also generate oxygen chemically by igniting Solid Fuel Oxygen Generation (SFOG) canisters comprised of lithium perchlorate. Each canister provides the oxygen needed to support one crew member for one day. **KK**

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SPACE EXPLORATION

Is it true the Russians built a space shuttle?

Timothy Ball

They did indeed, although it was less of a success than NASA's Space Shuttle. In 1988 the Soviet-built Buran spacecraft took flight, nearly identical in both its design and functionality to NASA's Space Shuttle. Its only launch in 1988 saw it take off on the heaviest ever liquid-fuelled rocket, Energia, and complete two automated orbits of Earth before landing. The programme was scrapped in 1993 following the dissolution of the USSR. Sadly, the sole Buran shuttle was destroyed in 2002 when a hangar in which it was stored at the Baikonur Cosmodrome collapsed. **JOC**

The Buran was transported atop an Antonov An-225

SOLAR SYSTEM

Could we detect an alien probe in our Solar System?

Rab Manderson

On Earth it's quite easy to detect the Voyager probe, but we know where to look and what we are looking for. Scour the region for a specific radio frequency and Voyager sticks out like a sore thumb. Would detecting an alien probe be as easy, though?

Probably not. Voyager is built to get a signal back to Earth, so constantly ensures its radio antenna points towards us – no mean feat. If an alien probe had a focused radio signal like Voyager, the chance of it pointing straight at us is very small. Ultimately, it would be extremely difficult, but not impossible, to detect an alien probe in our Solar System. **JB**

DEEP SPACE

Is there a guarantee of alien life?

Bill Norman

In 1961, a scientist called Frank Drake came up with an equation to predict the number of 'communicative' intelligent civilisations in our galaxy at one time. In this case 'communicative' means 'able to communicate using radio signals'. The Drake Equation, as it became known, multiplies seven different variables to give an estimate of the number of alien civilisations. It is thought that life evolved on Earth as soon as conditions were conducive to surviving, but intelligent life took millions of years longer, so within the Drake equation the number of alien life forms tends to be much larger than the final number of 'communicative' civilisations. While it is impossible to 'guarantee' alien life simply by thinking about the number of Earth-like planets, using this logic implies that finding a place alien life exists will only take a small number of Earth-like planets, but finding intelligent alien life we can communicate with will be significantly more difficult! **MW**

Civilisations
Number of civilisations in our galaxy with which we might be able to communicate

Planets
The fraction of stars with planets

Life support
The fraction that go on to support life

Technology
Fraction of civilisations with a technology detectable from space

$$N = R^{*} \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

Star formation
Average rate of star formation per year in our galaxy

Life potential
Average number of planets (per star with planets) with potential to support life

Intelligent life
The fraction that go on to support intelligent life

Length of time
How long such civilisations release detectable signs of their existence into space

Quick-fire questions

@spaceanswers

How long would it take to travel from Jupiter to Mars?
Obviously, it depends on your speed and the distance between the two planets, which varies greatly. At Space Shuttle speed, the shortest trip would take approximately 1.8 years, and the longest 3.8 years.

How long did it take for Mariner 2 to reach Venus?
The flight time for NASA's Mariner 2 unmanned science probe was 3½ months from launch on 27 August 1962 to the Venus flyby on 14 December 1962.

How long has the Hubble telescope been in space?
The Hubble Space Telescope was carried to low Earth orbit aboard Space Shuttle Discovery on 24 April 1990 on the STS-31 mission.

What direction does the Earth revolve in?
The Earth rotates on its axis to the east in an anticlockwise direction, once every 24 hours.

When was the first space rover invented?
The first successful space rover was Lunokhod 1, built by the Soviet Union and which landed on the Moon on 17 November 1970.

What's the difference between a satellite and a probe?
A satellite refers to a spacecraft that is in orbit around a body, whether it is Earth or otherwise. A probe is a spacecraft that leaves Earth to explore space.

How many landings have we done on other worlds?
There have been 36 successful landings on other worlds: the Moon, Venus, Mars and Titan. Dozens of other landing attempts ended in failure.

worldmags

Quick-fire questions

@spaceanswers

Has anyone ever been injured by a meteorite?
The only person to ever be injured by an extraterrestrial object was Ann Elizabeth Hodges, who was hit on the hip by a piece of meteorite in 1954 in Oak Grove, Alabama.

What if the Earth was the size of a grape?
If this happened, to scale the Moon would be 40cm away, the Sun 150m and Jupiter 0.8km.

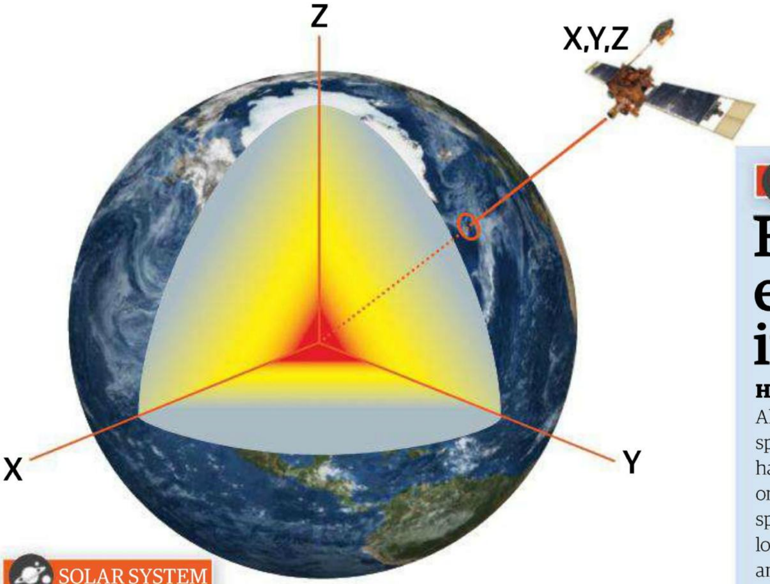
Can you fire a gun in space?
Yes, you can, since modern ammunition has its own oxidiser. The smoke trail, though, would expand like a sphere from the tip of barrel.

When was the first photo from space taken?
The first photo from space, looking back at Earth, was taken on 24 October 1946 by a camera riding on a V-2 rocket.

How many places could support life?
So far, we know of two worlds in the universe that have the right conditions for life: Earth and Saturn's moon Titan.

Does the Curiosity team operate on Mars time?
Yes, the Curiosity team have to shift their clocks back 40 minutes every day to ensure they operate on Martian time. Days on Mars are about 40 minutes longer than Earth days.

Can a moon have a moon?
In theory, yes, a moon can have its own moon, but one has never been discovered. Saturn's moon Rhea, however, might have its own ring system.



SOLAR SYSTEM

How do space craft navigate?

Jim Donald

With no magnetic field to rely on, a compass would be of no use. So scientists have devised a space co-ordinate system. This has the catchy name of the Earth Mean Equator and Equinox of Epoch J2000, abbreviated as EME2000.

The name effectively explains the reference points used for this system; a reference body (Earth); a reference plane (the mean equator); a reference direction (the vernal equinox, a line from Earth to the Sun on the first day of spring); and a reference time (J2000, or 1 January 2000, at 12:00:00). The reference time is included to compensate for minute motion in the reference planes due to gravitational forces.

Spacecraft use star-trackers to view reference constellations and celestial objects to place themselves within this system. Once the position is known, inertial systems (accelerometers and gyroscopes that can determine the orientation and relative motion of the craft) are used to calculate the course that the craft is on, and any adjustments that need to be made. **SA**

SPACE EXPLORATION

Has a plant ever grown in space?

Hannah Green

Almost since the dawn of the space age, plants and seeds have been taken into space on unmanned and manned spacecraft to study the effect of low or no gravity on plant growth and development. Future space explorers and colonists on long missions will need to cultivate their own food in greenhouses and use plants to supply oxygen to breathe. Right now, astronauts aboard the ISS are growing lettuce, peas, radishes, tree saplings and more in their own 'space gardens' to investigate if space-grown vegetables can be safely eaten by the crew and also enhance their well-being. **KK**

SOLAR SYSTEM

What would happen if Earth and Mars switched places?

Kirsty Ray Brown

If we were magically able to instantly switch the places of Earth and Mars, the results would be catastrophic. From a climate point of view, Martians would enjoy a noticeable increase in habitability. In Earth's position, at a closer point to the Sun, ice at the planet's poles would melt, bathing the Red Planet in water. The temperature would increase and gas would be released from the soil, thickening the atmosphere and making it nearly as warm as Earth is now. On the flip side, Earth would have half as much sunlight as now, and so the planet would freeze over. Our days would be up to an hour longer and we'd likely lose some of our atmosphere as well. It wouldn't be good news for us.

In terms of the motion of the planets, however, the results would be chaotic. The outer planets would likely remain the same, but Mercury's orbit would vary wildly in a giant ellipse. Likewise, the orbit of Mars in Earth's position would fluctuate greatly from near to far from the Sun. Only Earth and Venus would be able to retain a somewhat stable orbit in their positions. **JOC**

SPACE EXPLORATION

When was the first rocket invented?

Richard Tubbs

The inventor of the first rocket is a mystery lost to time, but it's believed that 9th Century Chinese alchemists invented gunpowder, which eventually led to bombs and rocket-propelled projectiles like cannonballs and arrows as well as the ubiquitous firecrackers. The use of terrorising and deadly rockets by Genghis Khan during his widespread conquests of Asia, Russia and Europe spread the knowledge of rocket technology across the globe. The obvious military advantages of rockets as weapons of war accelerated advances in their technological development to create ever more powerful, accurate and destructive versions. A key advance was the invention of the first liquid-fuelled rocket in 1926 by the American Robert Goddard in Auburn, Massachusetts. Goddard is considered to be one of the fathers of the modern rocket era. In the span of a few short decades this led to the German V-2 rockets and NASA's Saturn V liquid-fuelled rockets which landed the first human on the Moon, Neil Armstrong, in 1969. **KK**

DEEP SPACE

Will the universe be crushed or expand forever?

Anonymous

If the amount of 'stuff' (matter, energy, dark matter and any other materials we find) in the universe is too little, the universe will expand forever and the energy inside will become more and more spread out until the 'big freeze'. Everything stops, like an engine with no fuel. Particles can't interact and reactions don't take place as the energy required to do any of this is too thinly spread.

With just the right amount of 'stuff', the universe will expand until it reaches a balance point where all the matter is more spread out but expansion stops.

With too much 'stuff', the expansion rate is slowed to the point where gravity dominates and the universe collapses. This is sometimes called the 'Big Crunch', like a reverse Big Bang. With everything being concentrated back into the point of origin, things would be pretty bleak for us!

We don't yet know which fate will be ours. It could be that we go down a different path altogether. **JB**

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STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

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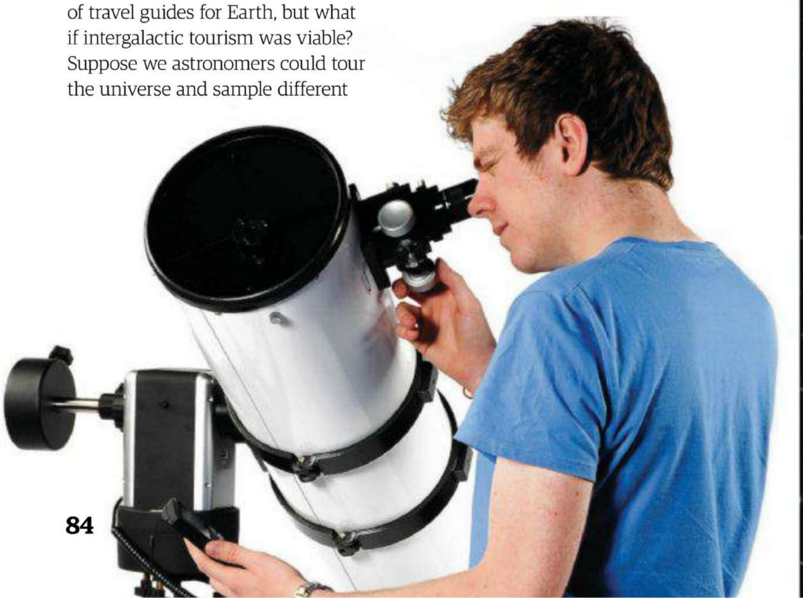
Observing the Milky Way

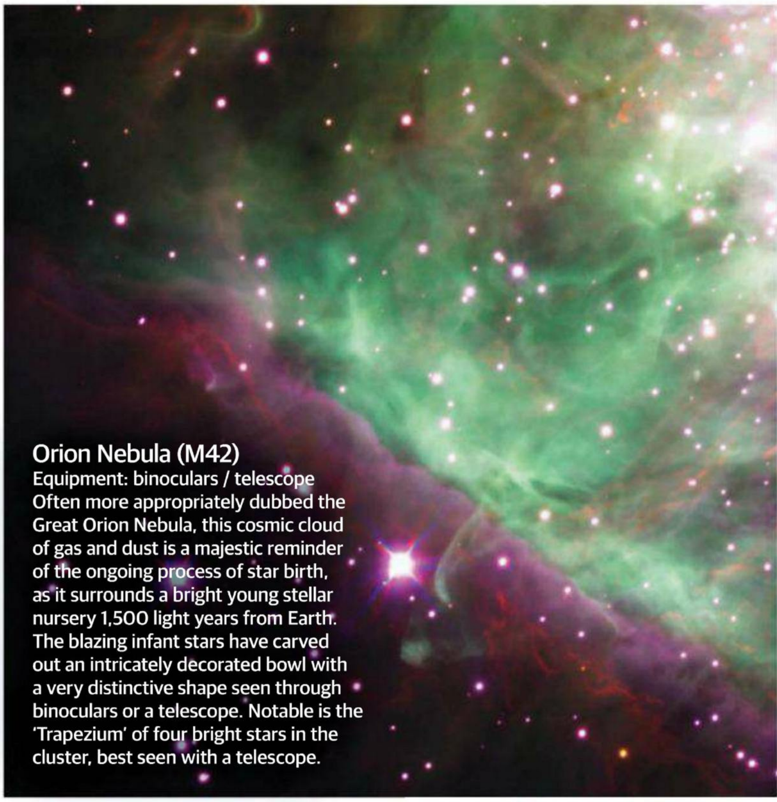
Aquaint yourself with some of the marvelous astronomical sights that await in the galaxy we call home

Welcome to the Milky Way. It's funny; you live here, but how often do you go out to see the sights? Just like any great city, our galaxy is replete with iconic historical monuments, relatively young creations, and some quirky curiosities. Naturally we consider a handful of these to be the absolute best for observers and photographers, just as we do with the Colosseum, Forum and St Peter's in Rome, for which holidaymakers have plenty of information available to get clued up on before they travel.

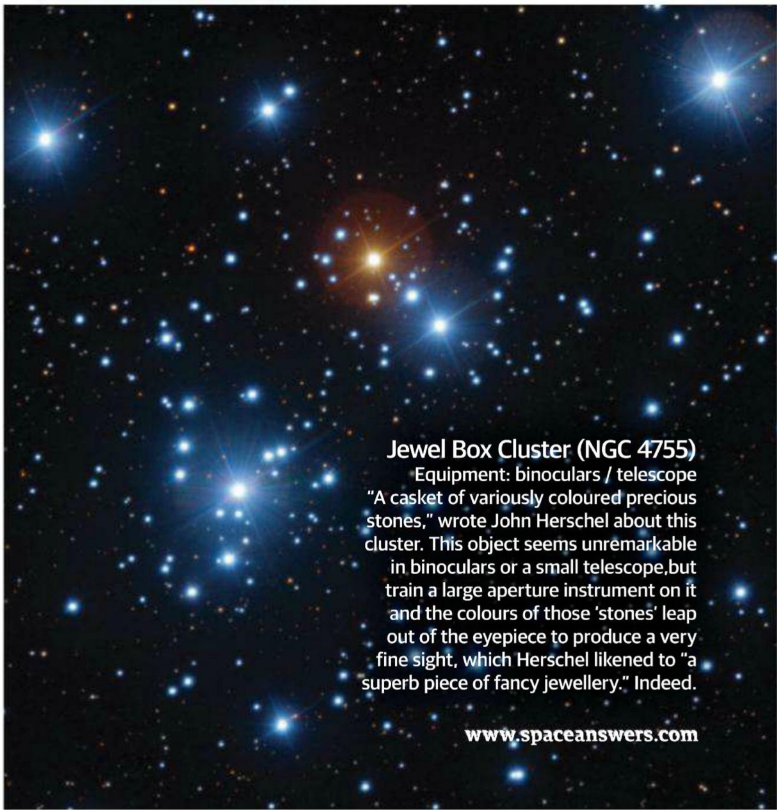
There's an entire industry surrounding the research and sale of travel guides for Earth, but what if intergalactic tourism was viable? Suppose we astronomers could tour the universe and sample different skies – perhaps, somewhere far away, there are intelligent beings that already do that (one wonders how they negotiate the time off with their employers!). If travel-writers visited us from another galaxy, say the neighbouring Andromeda spiral, what might they pick for their absolute must-see objects?

Unfortunately our perspective on the galaxy is limited – some of it is completely hidden from us – but if we were Andromedans backpacking through the Solar System, these eight popular gems would probably be on our bucket list. ■

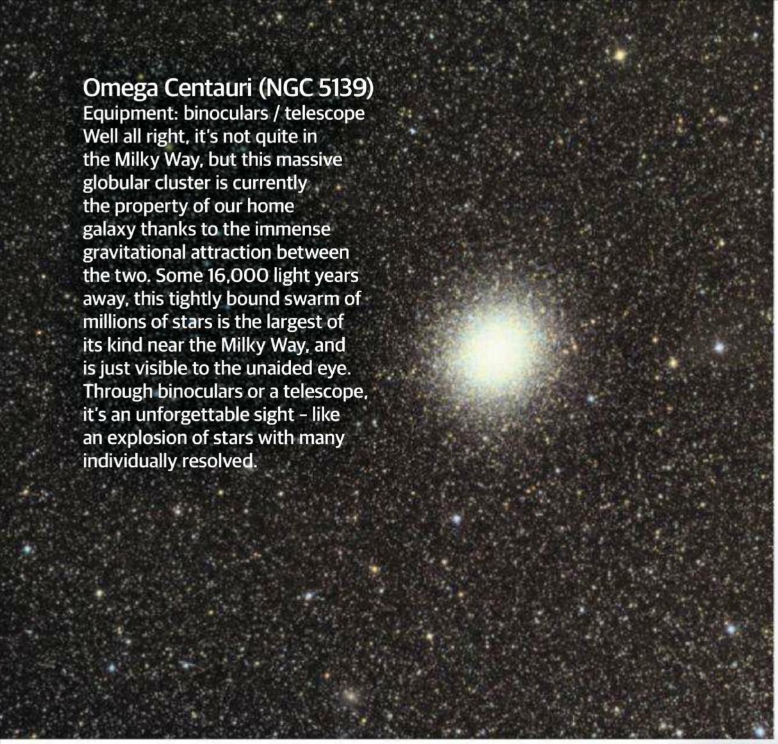




Orion Nebula (M42)
Equipment: binoculars / telescope
Often more appropriately dubbed the Great Orion Nebula, this cosmic cloud of gas and dust is a majestic reminder of the ongoing process of star birth, as it surrounds a bright young stellar nursery 1,500 light years from Earth. The blazing infant stars have carved out an intricately decorated bowl with a very distinctive shape seen through binoculars or a telescope. Notable is the 'Trapezium' of four bright stars in the cluster, best seen with a telescope.



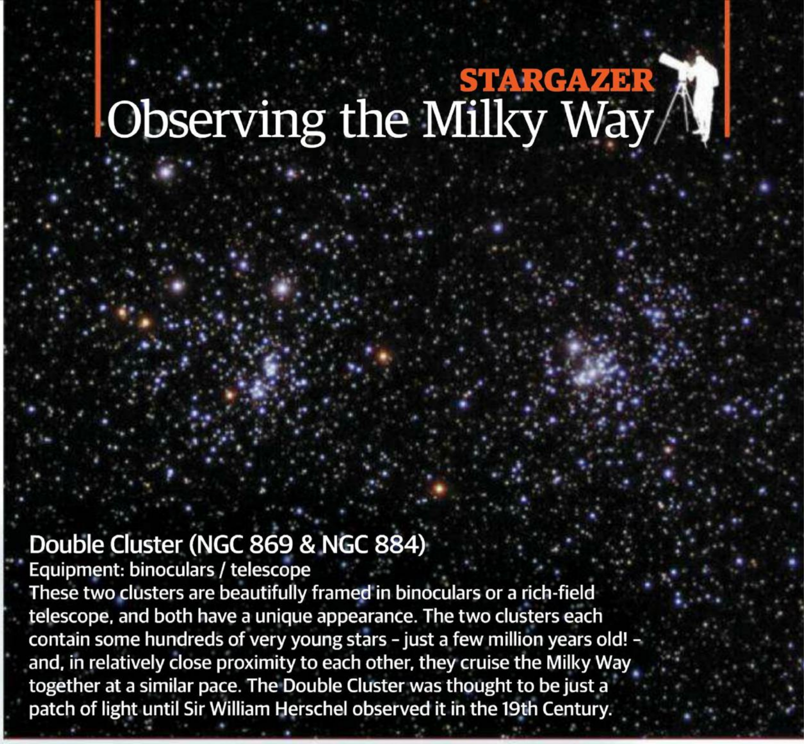
Jewel Box Cluster (NGC 4755)
Equipment: binoculars / telescope
"A casket of variously coloured precious stones," wrote John Herschel about this cluster. This object seems unremarkable in binoculars or a small telescope,but train a large aperture instrument on it and the colours of those 'stones' leap out of the eyepiece to produce a very fine sight, which Herschel likened to "a superb piece of fancy jewellery." Indeed.



Omega Centauri (NGC 5139)

Equipment: binoculars / telescope

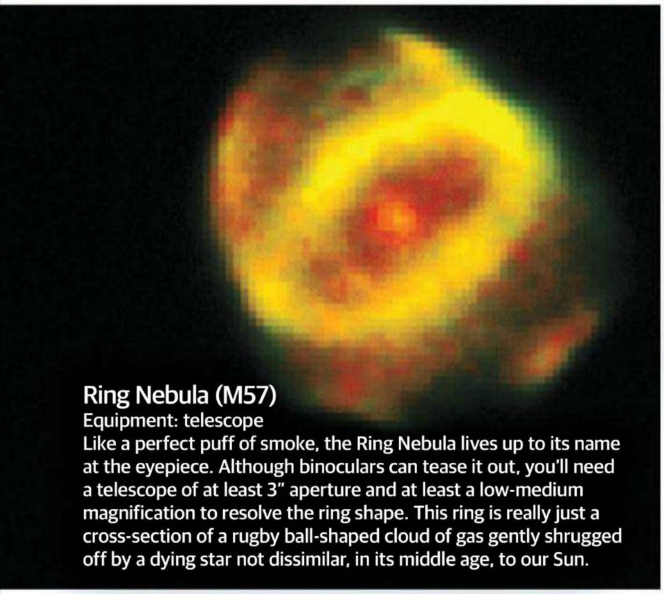
Well all right, it's not quite in the Milky Way, but this massive globular cluster is currently the property of our home galaxy thanks to the immense gravitational attraction between the two. Some 16,000 light years away, this tightly bound swarm of millions of stars is the largest of its kind near the Milky Way, and is just visible to the unaided eye. Through binoculars or a telescope, it's an unforgettable sight – like an explosion of stars with many individually resolved.



Double Cluster (NGC 869 & NGC 884)

Equipment: binoculars / telescope

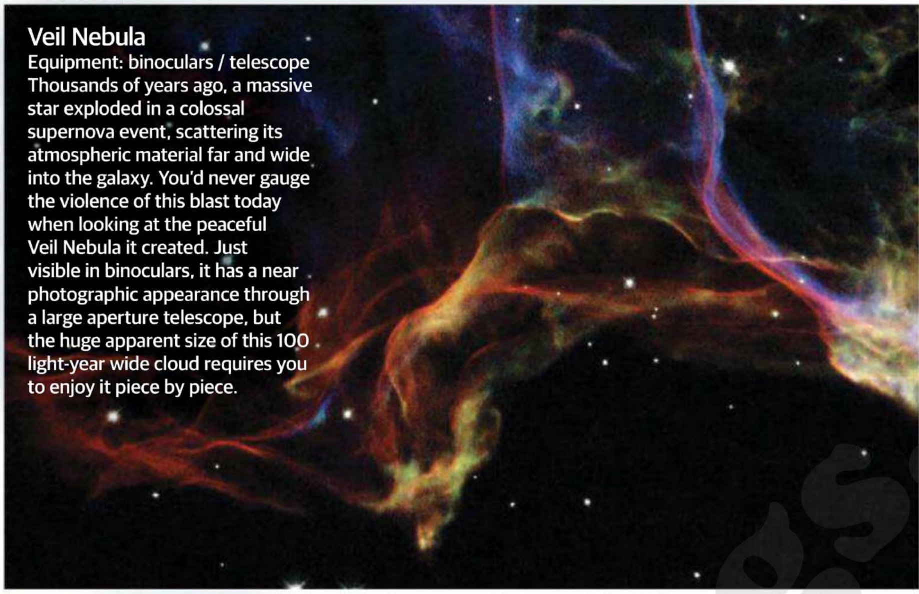
These two clusters are beautifully framed in binoculars or a rich-field telescope, and both have a unique appearance. The two clusters each contain some hundreds of very young stars – just a few million years old! – and, in relatively close proximity to each other, they cruise the Milky Way together at a similar pace. The Double Cluster was thought to be just a patch of light until Sir William Herschel observed it in the 19th Century.



Ring Nebula (M57)

Equipment: telescope

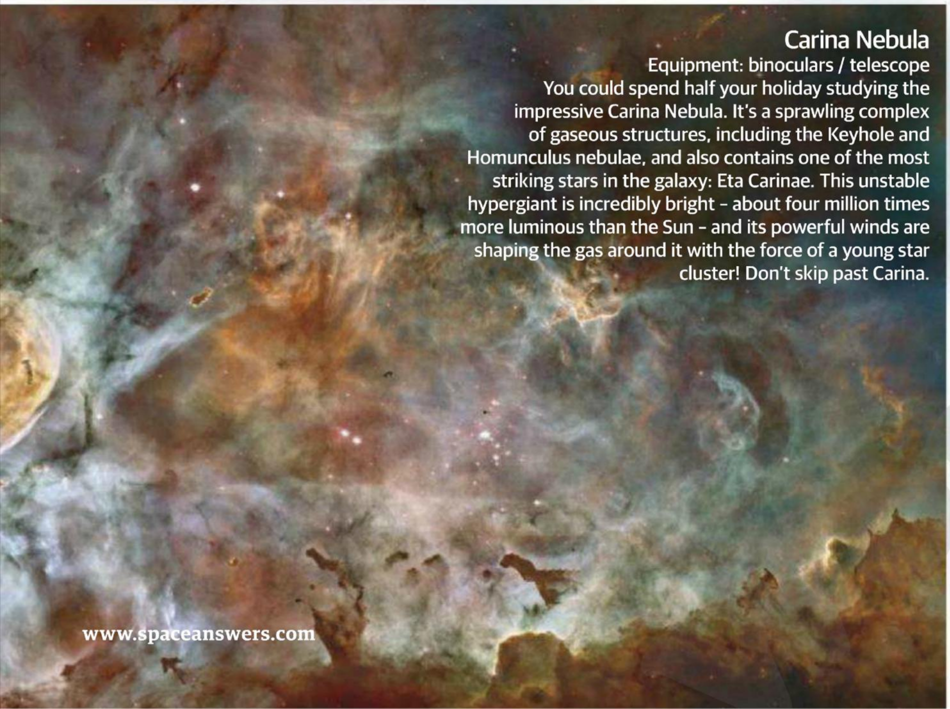
Like a perfect puff of smoke, the Ring Nebula lives up to its name at the eyepiece. Although binoculars can tease it out, you'll need a telescope of at least 3" aperture and at least a low-medium magnification to resolve the ring shape. This ring is really just a cross-section of a rugby ball-shaped cloud of gas gently shrugged off by a dying star not dissimilar, in its middle age, to our Sun.



Veil Nebula

Equipment: binoculars / telescope

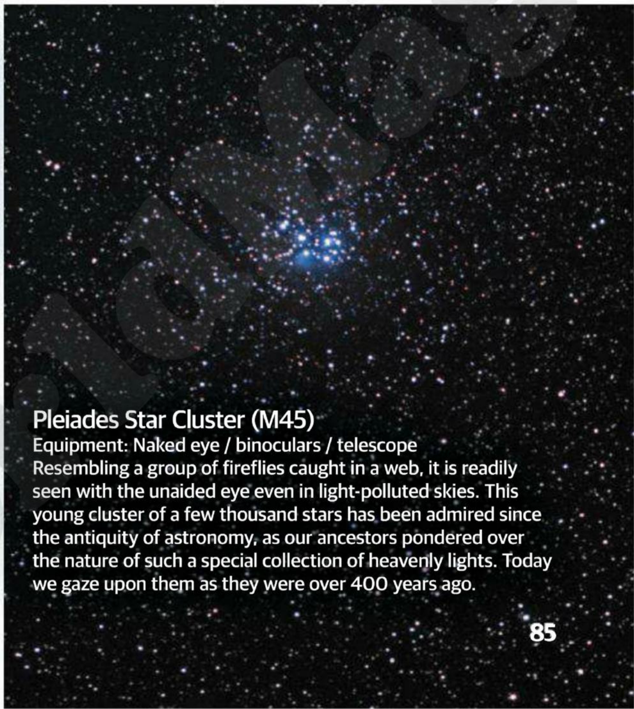
Thousands of years ago, a massive star exploded in a colossal supernova event, scattering its atmospheric material far and wide into the galaxy. You'd never gauge the violence of this blast today when looking at the peaceful Veil Nebula it created. Just visible in binoculars, it has a near photographic appearance through a large aperture telescope, but the huge apparent size of this 100 light-year wide cloud requires you to enjoy it piece by piece.



Carina Nebula

Equipment: binoculars / telescope

You could spend half your holiday studying the impressive Carina Nebula. It's a sprawling complex of gaseous structures, including the Keyhole and Homunculus nebulae, and also contains one of the most striking stars in the galaxy: Eta Carinae. This unstable hypergiant is incredibly bright – about four million times more luminous than the Sun – and its powerful winds are shaping the gas around it with the force of a young star cluster! Don't skip past Carina.



Pleiades Star Cluster (M45)

Equipment: Naked eye / binoculars / telescope

Resembling a group of fireflies caught in a web, it is readily seen with the unaided eye even in light-polluted skies. This young cluster of a few thousand stars has been admired since the antiquity of astronomy, as our ancestors pondered over the nature of such a special collection of heavenly lights. Today we gaze upon them as they were over 400 years ago.

What's in the sky?

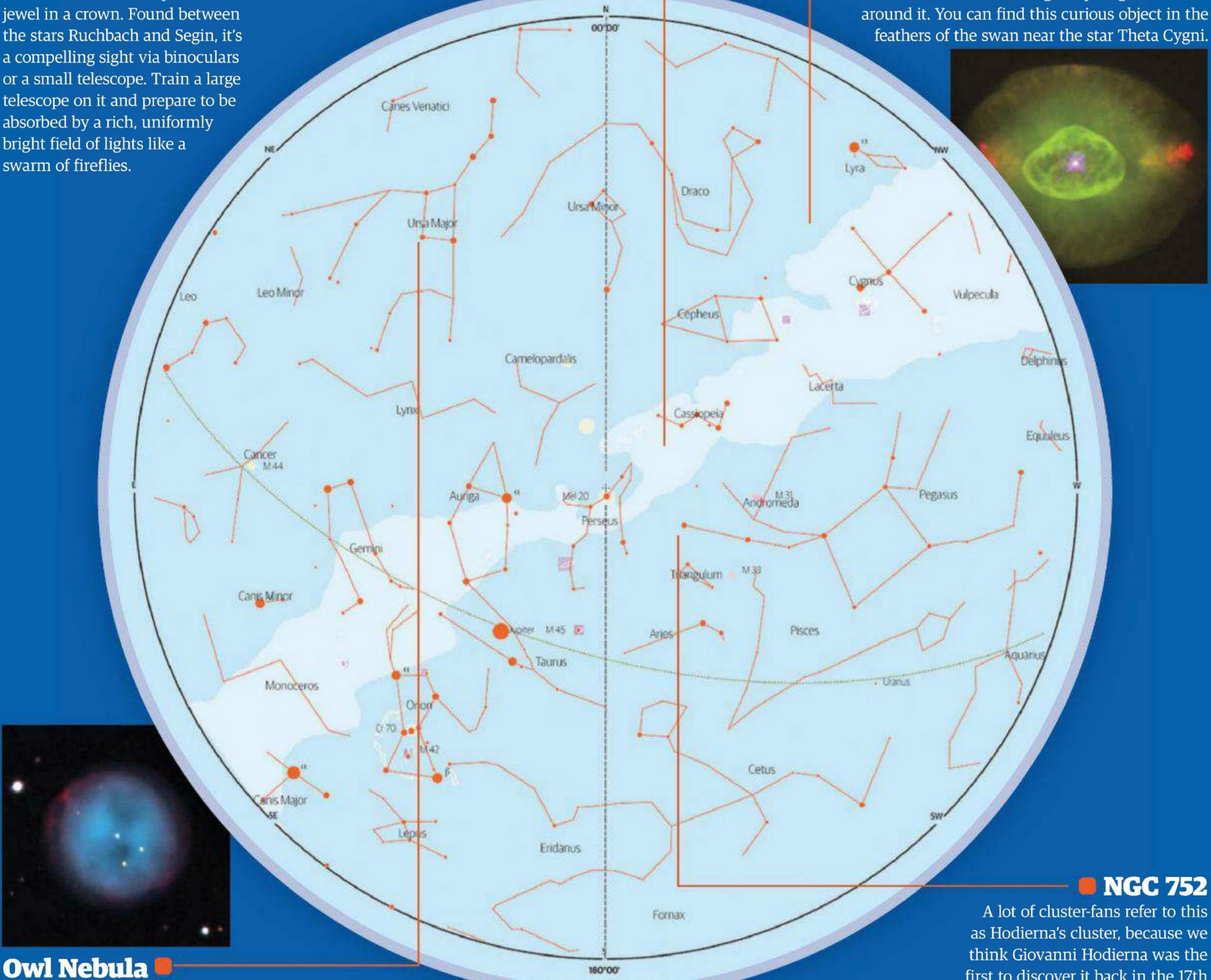
Whether you're using the naked eye, binoculars or a telescope, there's plenty to see. Here are some of the season's highlights...

NGC 663

This young cluster of a few hundred stars sparkles in the constellation of Cassiopeia like a jewel in a crown. Found between the stars Ruchbach and Segin, it's a compelling sight via binoculars or a small telescope. Train a large telescope on it and prepare to be absorbed by a rich, uniformly bright field of lights like a swarm of fireflies.

Blinking Nebula (NGC 6826)

Why does this little nebula blink when seen through a telescope? It's an illusion caused by the bright central star overwhelming the pale gas and dust around it. You can find this curious object in the feathers of the swan near the star Theta Cygni.



Owl Nebula (M97 or NGC 3587)

You'll need a large telescope to understand the name, but even a small telescope will reveal a hint of this popular planetary nebula in Ursa Major. Its big eyes gaze at us from over 2,500 light years away, but studies show it's been watching for less than 6,000 years. This is a young nebula. It sits within a couple of degrees from Merak.

NGC 752

A lot of cluster-fans refer to this as Hodierna's cluster, because we think Giovanni Hodierna was the first to discover it back in the 17th century. Then for over 100 years it was lost or forgotten, only to be rediscovered by none other than Caroline Herschel in 1783. Look for it in Andromeda, around five degrees south-west of the star Almaak in the direction of Triangulum.

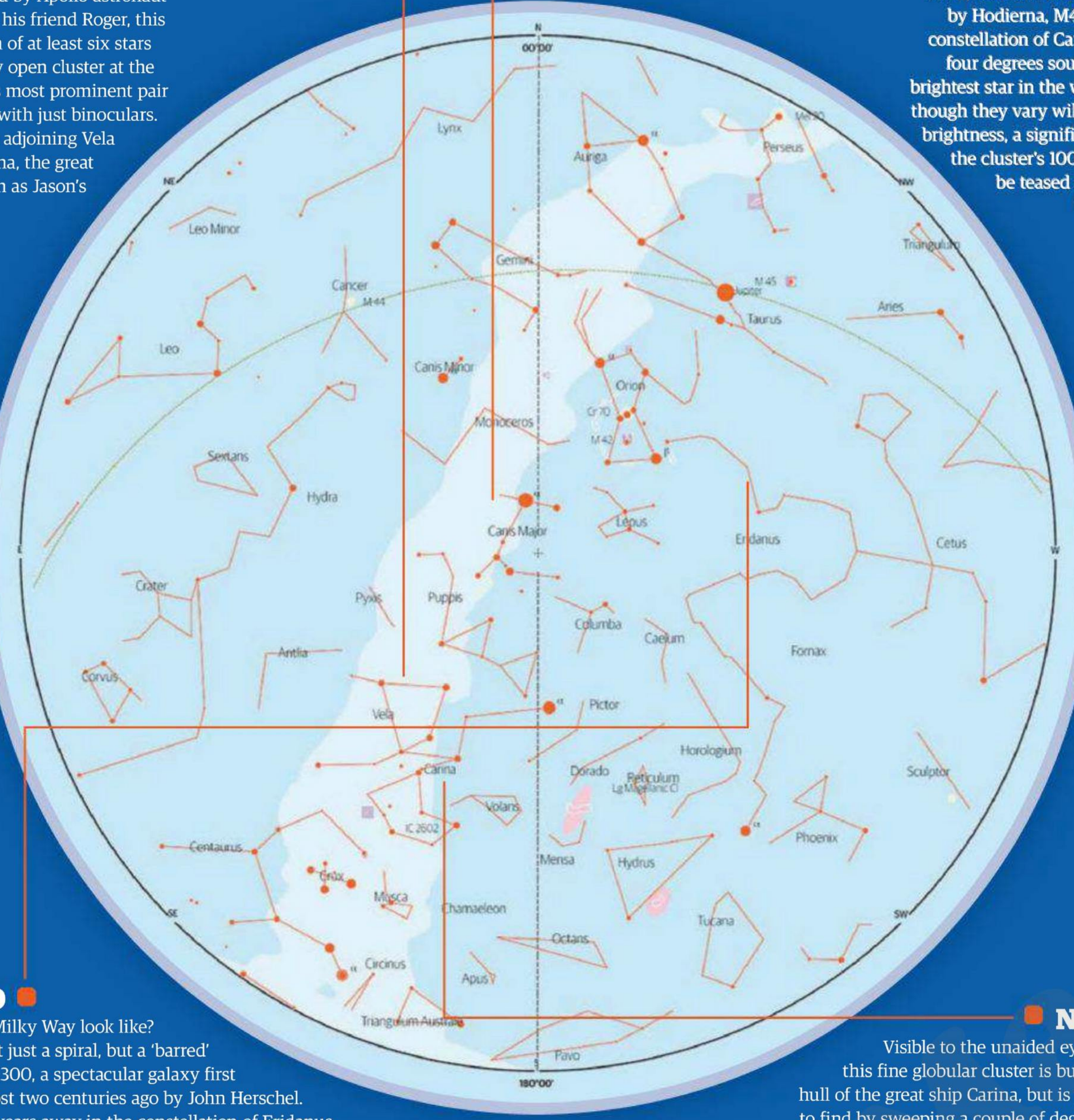
Northern hemisphere
00.00 UTC
15 November 2012

Regor (Gamma Velorum)

Famously named by Apollo astronaut Gus Grissom for his friend Roger, this beautiful system of at least six stars appears as a tiny open cluster at the eyepiece, and its most prominent pair are readily split with just binoculars. Regor is the star adjoining Vela (the sail) to Carina, the great ship once known as Jason's Argo Navis.

M41

One of the greatest open clusters of all, and another first discovered by Hodierna, M41 glitters in the constellation of Canis Major about four degrees south of Sirius, the brightest star in the whole sky. Even though they vary wildly in apparent brightness, a significant number of the cluster's 100 or so stars can be teased out with a rich-field telescope.



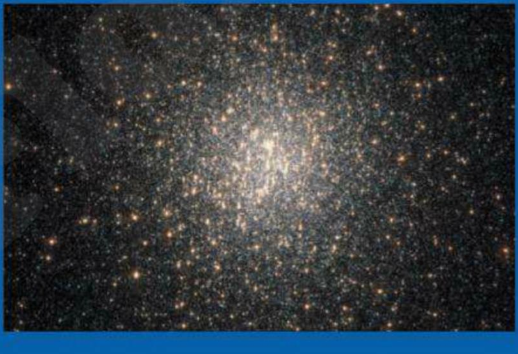
Southern hemisphere 00.00 UTC 15 December 2012

NGC 1300

What does the Milky Way look like? We know it's not just a spiral, but a 'barred' spiral like NGC 1300, a spectacular galaxy first discovered almost two centuries ago by John Herschel. 61 million light years away in the constellation of Eridanus (the river), NGC 1300 is also similar in size to our home galaxy, and can be seen with a large telescope. Look just over two degrees north of 16 Eridani.

NGC 2808

Visible to the unaided eye in dark skies, this fine globular cluster is buried within the hull of the great ship Carina, but is perhaps easiest to find by sweeping a couple of degrees north-east from the star Alpha in the neighbouring constellation of Volans (the flying fish). In binoculars or a telescope, some of its 1 million stars can be individually resolved.

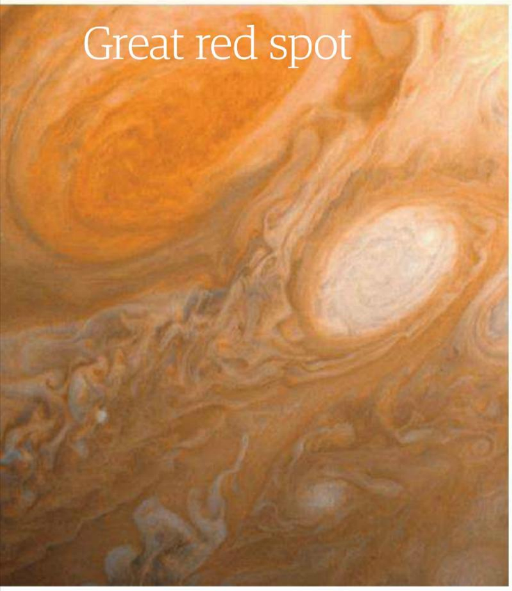


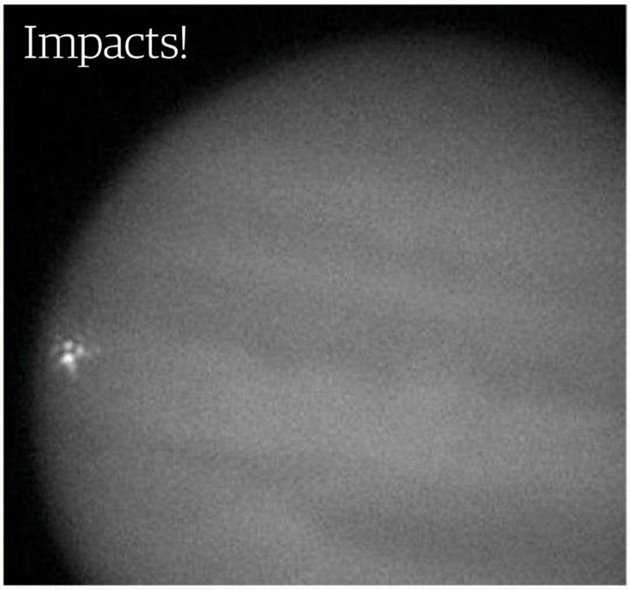
10 great sights on Jupiter

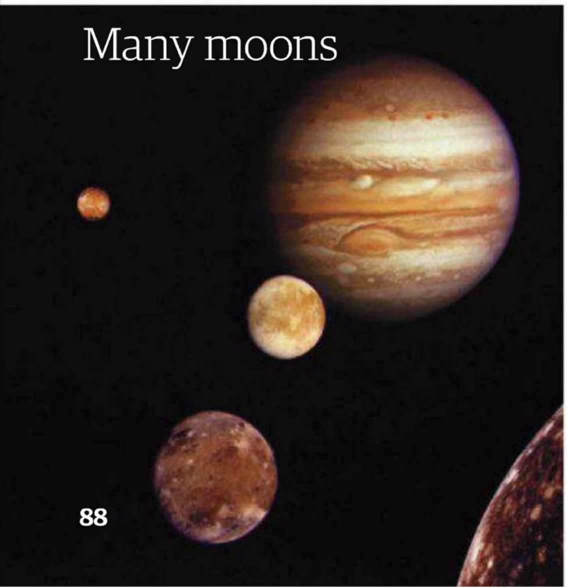
The largest planet in the Solar System is one of the most exciting places to point your telescope

Early next year, Jupiter will be perfectly placed in the evening sky for observers all over the world, drifting among the stars of Taurus the bull. The mighty planet's disk and four largest natural satellites can be glimpsed using just a pair of binoculars, but with a small telescope and high-power eyepiece, you'll be well on your way to exploring the Jovian system in meticulous detail, from the great swirling storms in Jupiter's cloud tops, to the shadows cast by distant moons.

Over 400 years ago, Galileo made history as the first to ever observe Jupiter with a telescope, and you can follow in his footsteps, albeit with a much better instrument. Even a modest pair of binoculars will outperform his telescope! At a distance of more than 390 million miles, it's amazing to appreciate how much detail we can glean when observing the dynamic Jupiter from our own gardens. Here are the top ten sights to look out for. ●







Jargon Buster

Meridian

As viewed from Earth, the meridian is a vertical line running through the apparent centre of Jupiter's disk. It's useful to predict the times when features of interest, such as the Great Red Spot, are on the meridian, as this is when they will be best visible. When a feature is on the meridian, as well as visible from your location, that's the time to take a look!

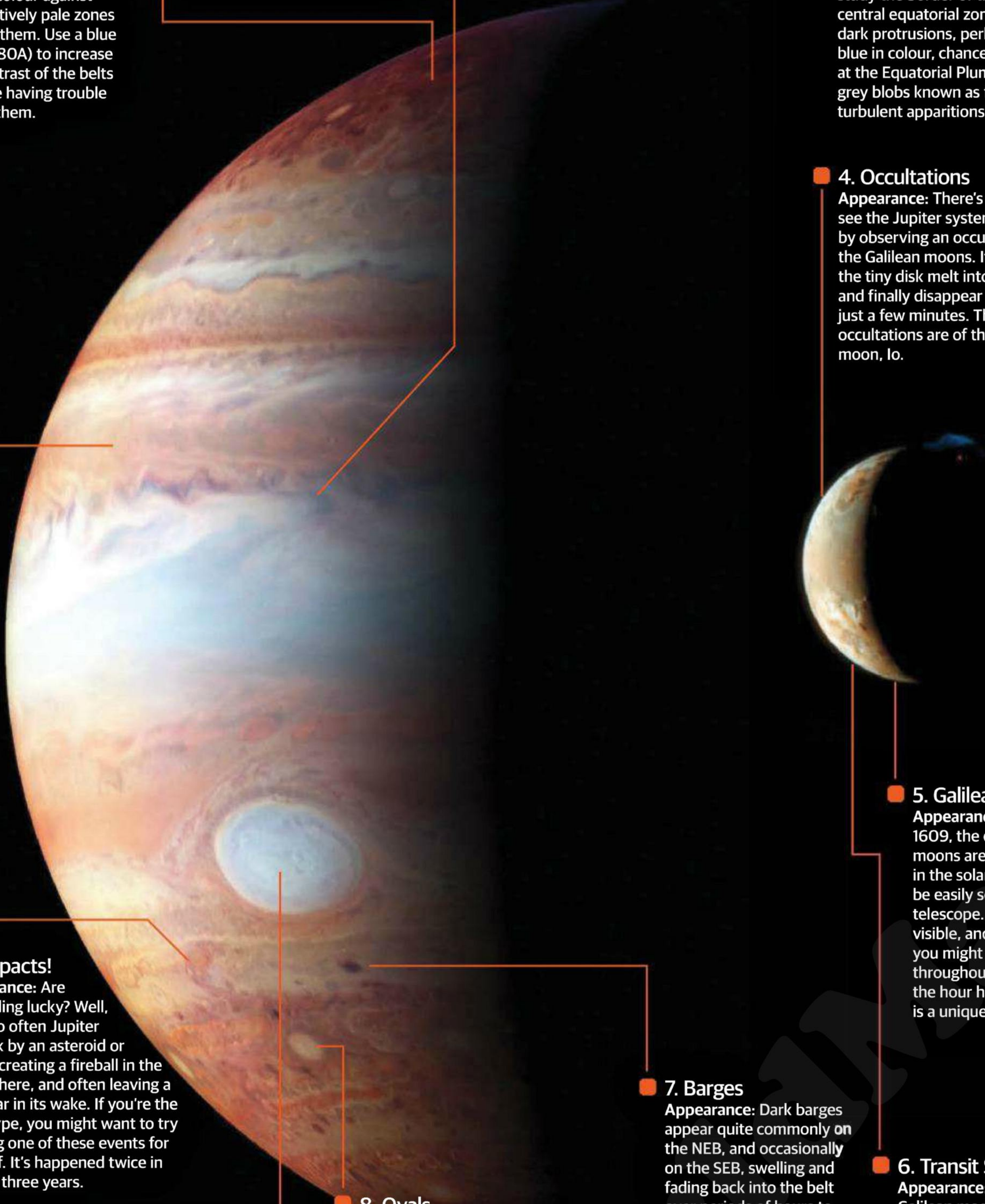
Cyclone & Anticyclone

Jupiter is covered with rotating vortices; storms often thousands of miles wide. Whether or not they are cyclonic or anticyclonic depends on latitude and direction of rotation. A storm rotating anticlockwise in the Northern Hemisphere, and clockwise in the Southern Hemisphere is a cyclone. An anticyclone fits the opposite description.

Blue Filter (#80A)

Coloured filters are a great tool for observers who wish to tamper with the relative contrast of particular surface features. Each colour is assigned a number, and number 80A represents a medium blue, which has become very popular for Jupiter observing. Sometimes it's known as a 'Jupiter filter'! It darkens the appearance of the planet's belts and festoons, as well as the intricate detail surrounding the larger storms.

10 great Jupiter sights



1. Equatorial Belts

Appearance: Easily the most prominent feature on the disk, Jupiter's North and South Equatorial Belts (NEB & SEB) are streams of thin, low altitude cloud, showing a deep orange-brown colour against the relatively pale zones around them. Use a blue filter (#80A) to increase the contrast of the belts if you're having trouble seeing them.

2. Polar Regions

Appearance: Notice the subtle differences in colour, with the South Polar Region appearing slightly darker, and if you like a challenge, hunt for spots at the extreme latitudes. In 2009, the SPR was struck by a sizeable object leaving a dark scar behind.

3. Festoons

Appearance: Whenever you look at Jupiter's equatorial belts, take time to study the border of the NEB with the central equatorial zone. If you see any dark protrusions, perhaps even slightly blue in colour, chances are you're looking at the Equatorial Plumes, which separate grey blobs known as festoons. Their turbulent apparitions are short-lived!

4. Occultations

Appearance: There's no better way to see the Jupiter system in motion than by observing an occultation of one of the Galilean moons. It's striking to see the tiny disk melt into the planet's limb and finally disappear over the course of just a few minutes. The most common occultations are of the innermost moon, Io.

5. Galilean Moons

Appearance: Discovered in 1609, the eponymous Galilean moons are among the largest in the solar system, and can be easily seen in a small telescope. All four are often visible, and if you're patient you might see them move throughout the evening, like the hour hand on a clock. Each is a uniquely fascinating world!

6. Transit Shadows

Appearance: When one of the Galilean moons transits the disk, you can be sure a shadow isn't far from it. In fact, with a small telescope you'll probably glimpse the shadow first! If you see a tiny black spot, look around for the culprit. Transits are an exciting sight for any Jupiter enthusiast!

7. Barges

Appearance: Dark barges appear quite commonly on the NEB, and occasionally on the SEB, swelling and fading back into the belt over periods of hours to days. Much like the belts, their dark appearance is due to low pressure and transparently thin top-layer clouds failing to sufficiently cover them up. Barges are sometimes mistaken for the GRS!

8. Ovals

Appearance: White ovals are often spotted in the south. One collection of ovals, formed in 1939, famously merged into 'Oval BA' in March 2000, a second red spot in the SEB. Unlike cyclonic barges, white ovals are predominantly anticyclonic in nature.

9. Great Red Spot

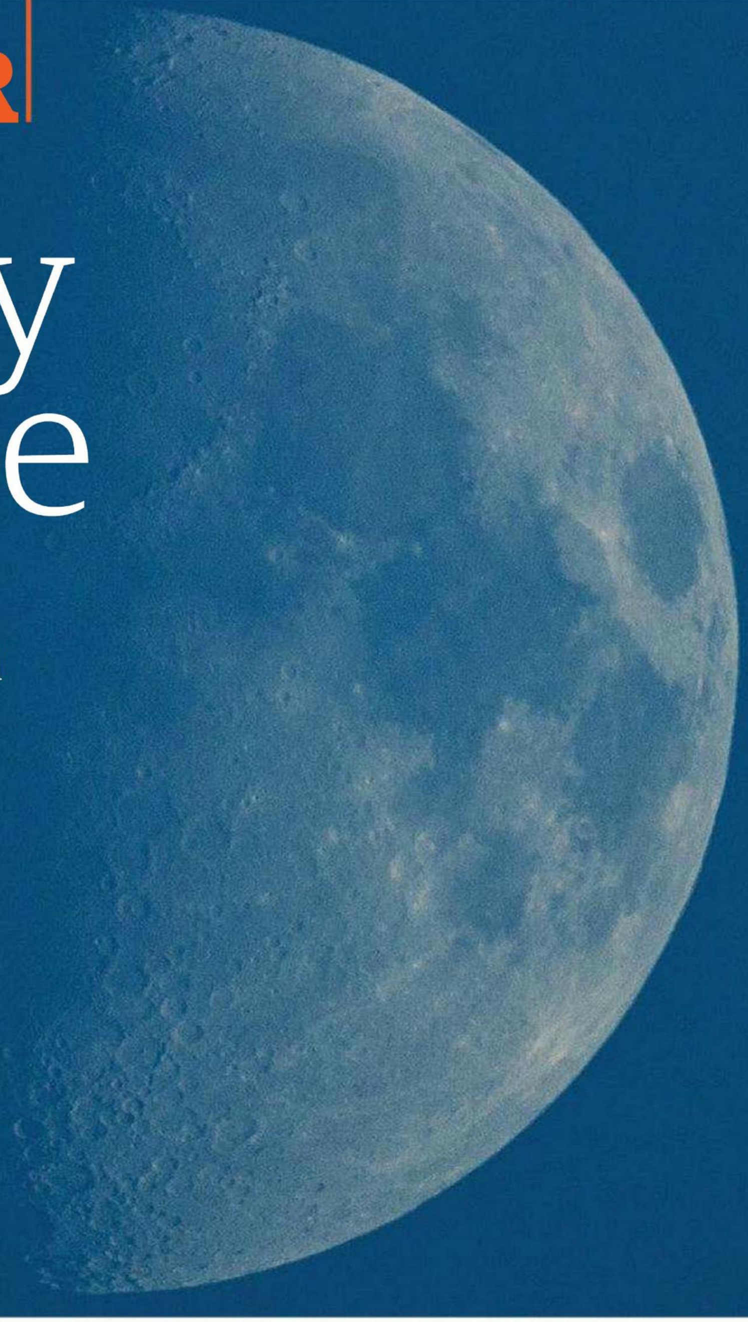
Appearance: Discovered by Jean-Dominique Cassini in 1655, the Great Red Spot (GRS) is a massive storm that's been raging for over 350 years. It cruises in the SEB, rotating over a period of days, churning the clouds in a tremendous anticyclonic vortex!

10. Impacts!

Appearance: Are you feeling lucky? Well, every so often Jupiter is struck by an asteroid or comet, creating a fireball in the atmosphere, and often leaving a dark scar in its wake. If you're the lucky type, you might want to try spotting one of these events for yourself. It's happened twice in the last three years.

Me & My Telescope

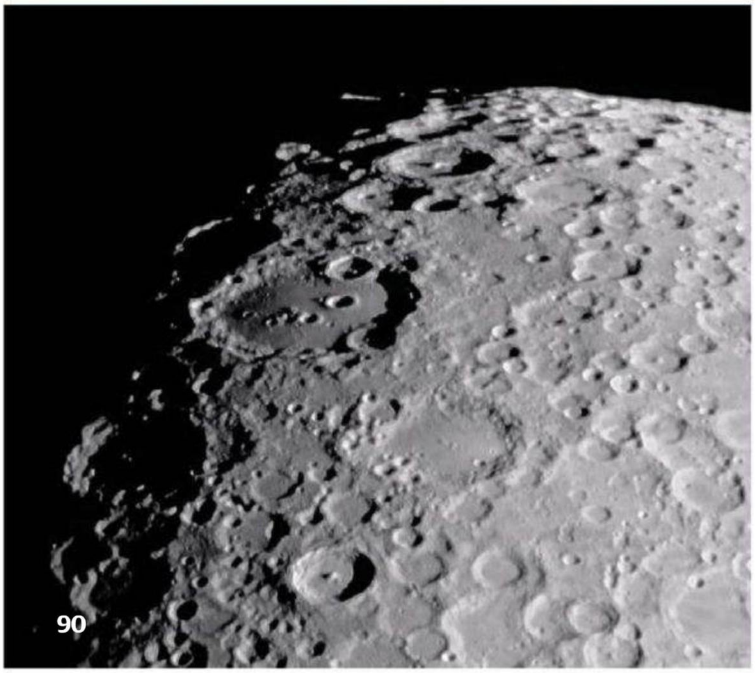
Send your astronomy photos or pictures of you with your telescope to **photos@spaceanswers.com** and we'll showcase them every issue

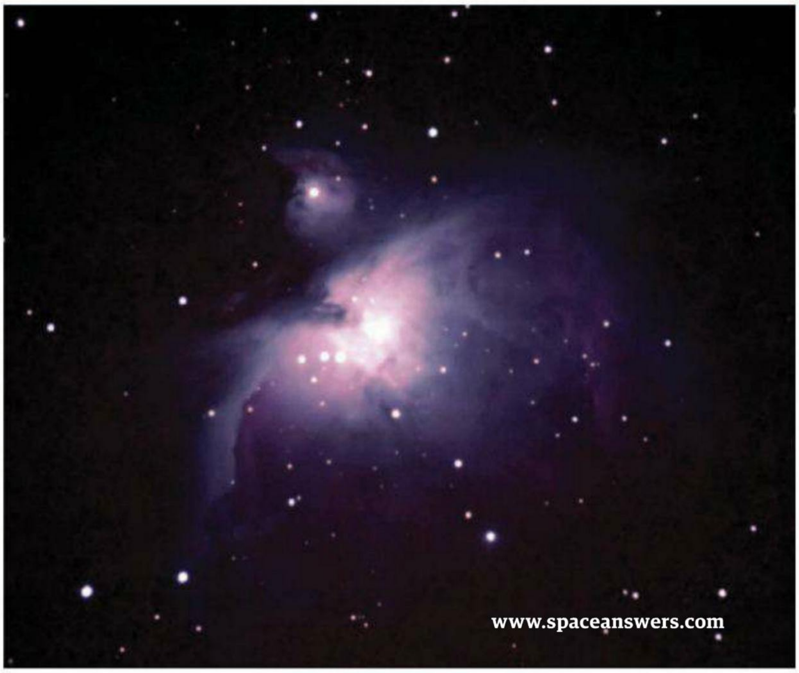


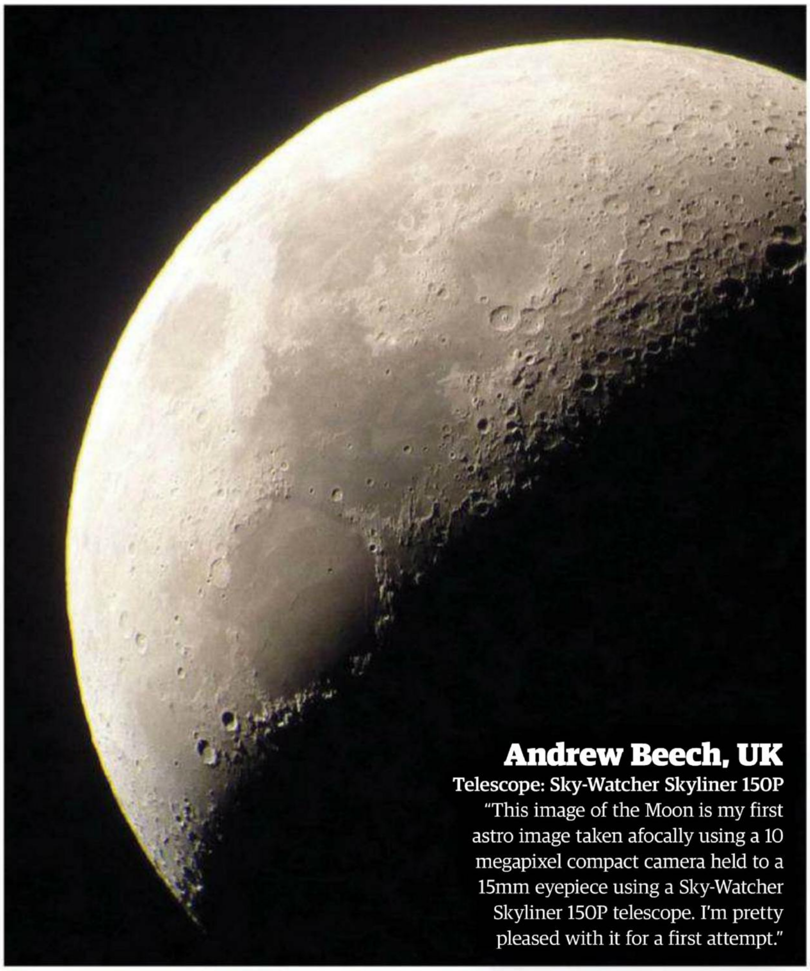
Paul Wharton, Craigavon, NI

Telescope: Sky-Watcher 200P

"My telescope is a Sky-Watcher 200P eight-inch Newtonian on an EQ5 mount with GOTO. This was taken at Craigavon Lakes in County Armagh, Northern Ireland, on my unsuccessful viewing attempt of the Venus transit. I use it for both viewing and webcam imaging and find it a good all-rounder. I use a Philips 840k flashed to SPC900 firmware for most images, but I've also adapted an Xbox Live camera and a Trust WB-5400. I've included a shot of Clavius taken with the Trust webcam too."



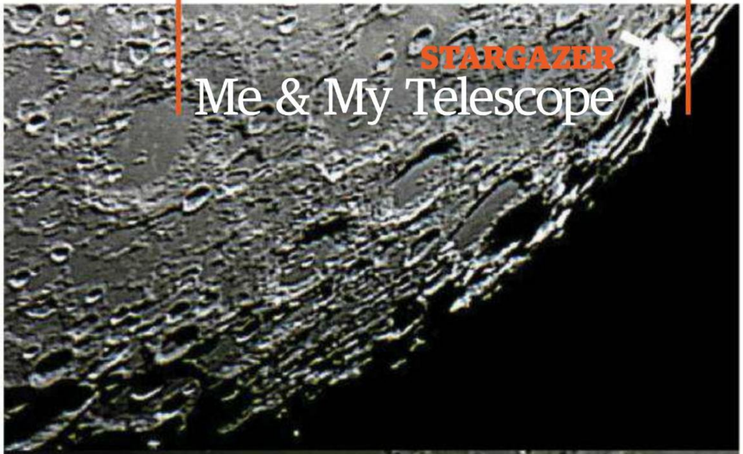




Andrew Beech, UK

Telescope: Sky-Watcher Skyliner 150P

"This image of the Moon is my first astro image taken afocally using a 10 megapixel compact camera held to a 15mm eyepiece using a Sky-Watcher Skyliner 150P telescope. I'm pretty pleased with it for a first attempt."



Alan Ackerley, UK

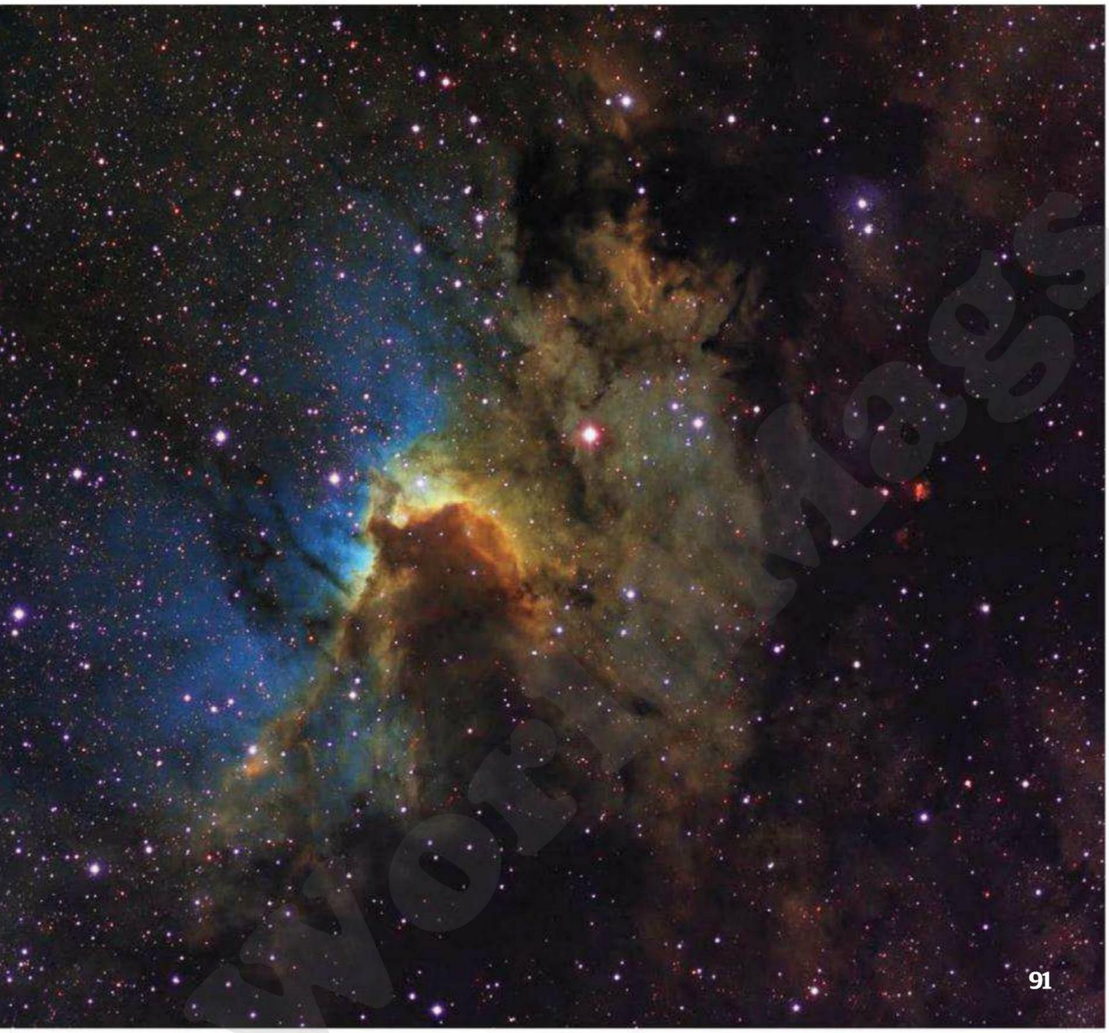
Telescope: Sky-Watcher Explorer-130P

"Late last year I was bought by my very nice wife a Sky-Watcher Explorer-130P SynScan AZ GOTO. I think she saw it as a cunning way to get me out of the house! Within a month, I had added a Philips SPC900 Astro Cam to my firepower together with some capture and stacking software. I then spent many nights out in the garden capturing images of the Moon and Jupiter. I suspect that to the purist eye these images were very average, but to me they were a spectacular achievement."

Gordon Haynes, Hereford, UK

Telescope: Paramount ME, Takahashi FSQ106ED

"I've been interested in astronomy for most of my life but about five years ago I started taking it more seriously. I specialise in narrow band imaging using the HST palette. I have changed equipment over the years and am currently using a Paramount ME, Takahashi FSQ106ED, FLI Atlas focuser, FLI ML8300 camera and filter wheel, Lodestar and OAG for guiding and Astrodon filters. This particular image is of SH2-155, the Cave Nebula, using the HST palette with a total exposure time of 24 hours."



Telescope advice

At under £300, this month's telescopes would be perfect for those just getting started in astronomy. But are they any good?

Celestron PowerSeeker 114 EQ

Cost: £133
From: www.hama.co.uk
Type: Reflector
Aperture: 114mm
Focal Length: 900mm
Mount: 269x

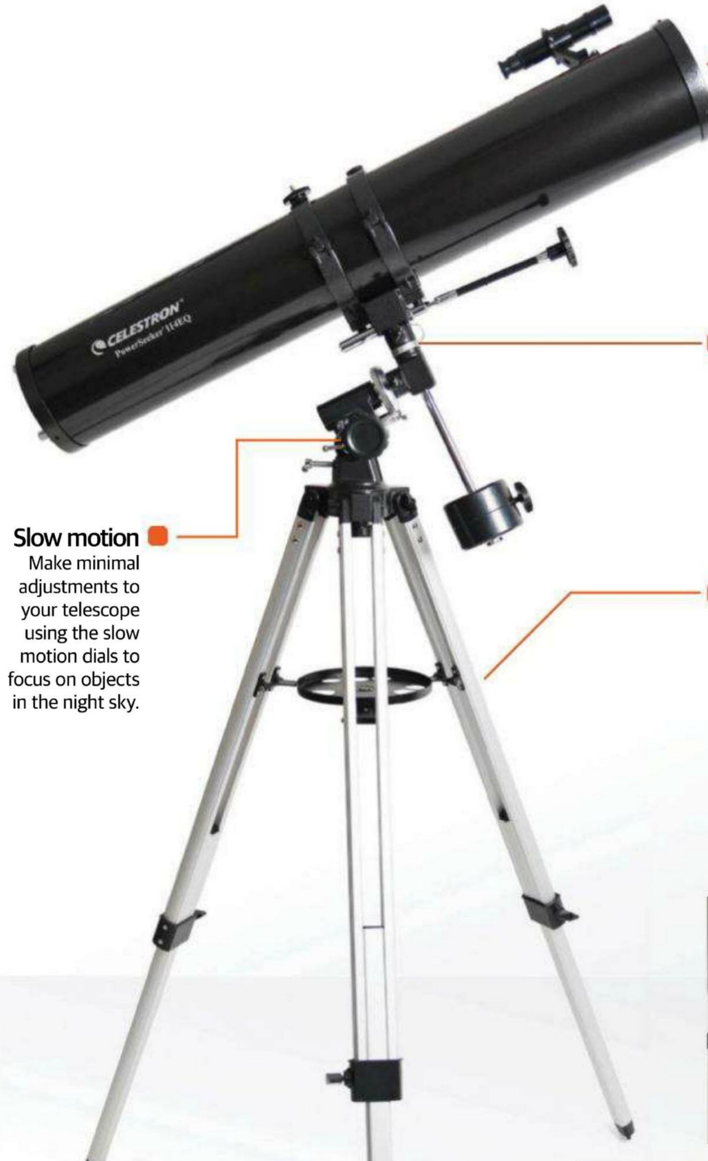
Aspiring astronomers will get a great kick out of Celestron's PowerSeeker range, and none more so than the 114 EQ which is a great way to view the cosmos at a reasonable budget.

Like most equatorial mount telescopes, the PowerSeeker can be a little fiddly to set up but once you've got it together its intricate design and slow motion controls will let you accurately track objects in the night sky with ease.

The glass optical components will make your images bright and clear, and an included 3x Barlow lens will increase the magnifying power of your eyepieces threefold so you can get those extra-close views of terrestrial and deep space objects. A handy accessory tray will also provide you with easy access to all of your eyepieces and lenses.

With the 114 EQ you'll be able to observe decent views of Saturn's rings and even its largest moon, Titan, in addition to other terrestrial objects such as the Moon and Mars. However, as an amateur, getting to grips with an equatorial mount can be difficult but master the techniques and you'll soon be having great fun observing the night sky.

"With the PowerSeeker you'll be able to observe decent views of Saturn's rings and even its largest moon, Titan"



Aperture
The 114mm aperture does a good job of capturing light from celestial objects.

Mount
Equatorial mounts can be quite difficult to set up and use, but master them and you'll soon be a capable astronomer.

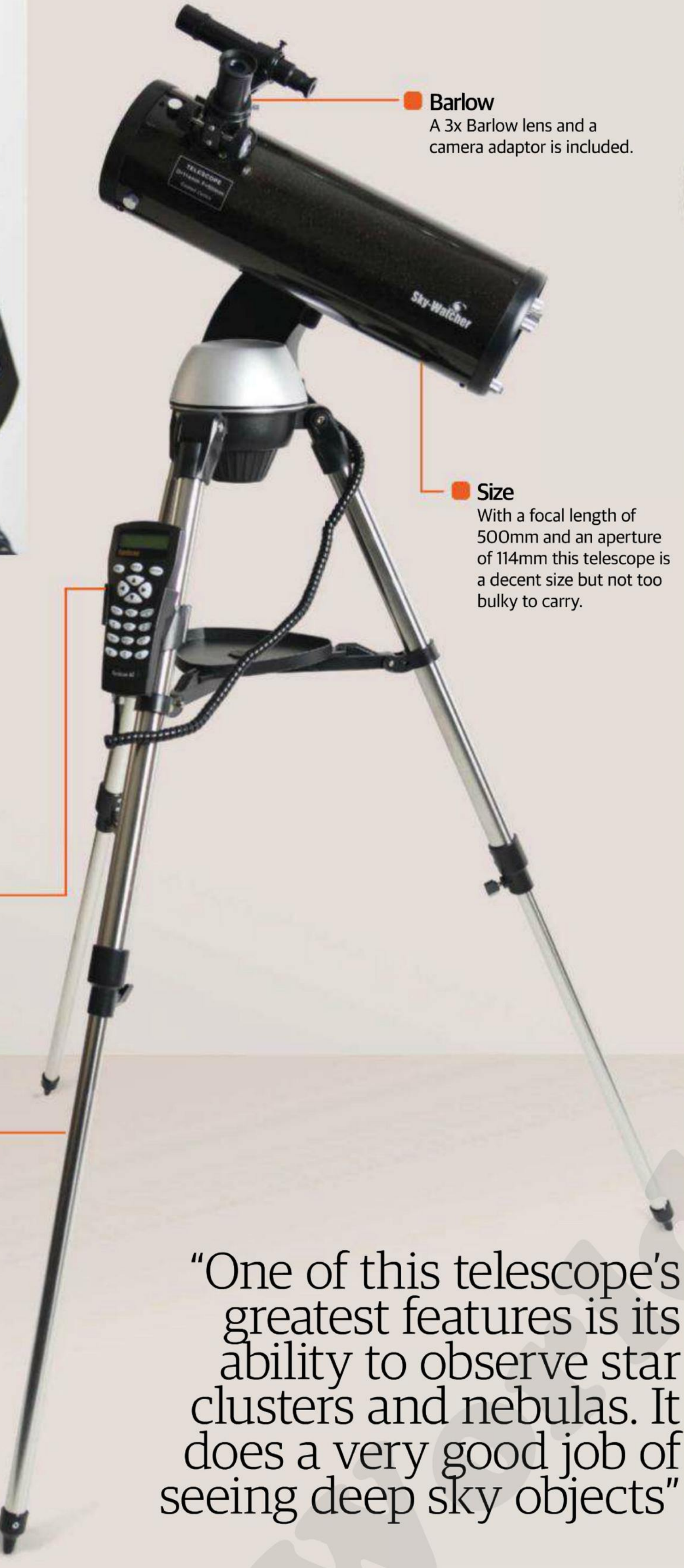
Slow motion
Make minimal adjustments to your telescope using the slow motion dials to focus on objects in the night sky.

Tripod
The aluminium tripod is pre-assembled and comes with an accessory tray.

The accessory tray is a very useful addition

The PowerSeeker 114 EQ can be a little tricky to set up

The 1145P has thousands of objects built in to its database

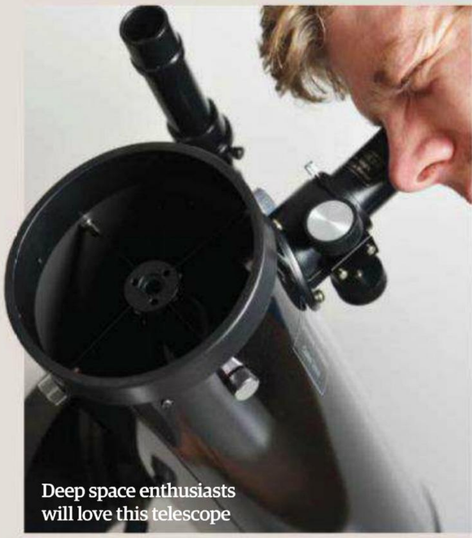


Barlow
A 3x Barlow lens and a camera adaptor is included.

Size
With a focal length of 500mm and an aperture of 114mm this telescope is a decent size but not too bulky to carry.

SynScan
This computerised telescope can find tens of thousands of objects for you in the night sky.

Tripod
The pre-assembled stainless steel tripod is sturdy and easy to use.



Deep space enthusiasts will love this telescope

Sky-Watcher Skyhawk 1145P SynScan

Cost: £260
From: www.sherwoods-photo.com
Type: Reflector
Aperture: 114mm
Focal Length: 500mm
Mount: x50

This computerised parabolic Newtonian reflector is not only a snap to set up but also a breeze to use, providing an excellent grounding for both amateur and experienced astronomers to get a great view of the cosmos.

The Skyhawk 1145P comes with a SynScan Altazimuth GoTo Mount, which will automatically find objects of interest for you in the night sky thanks to its large database of thousands of objects. You'll be able to observe planets in the Solar System with ease, with the Skyhawk providing great terrestrial views.

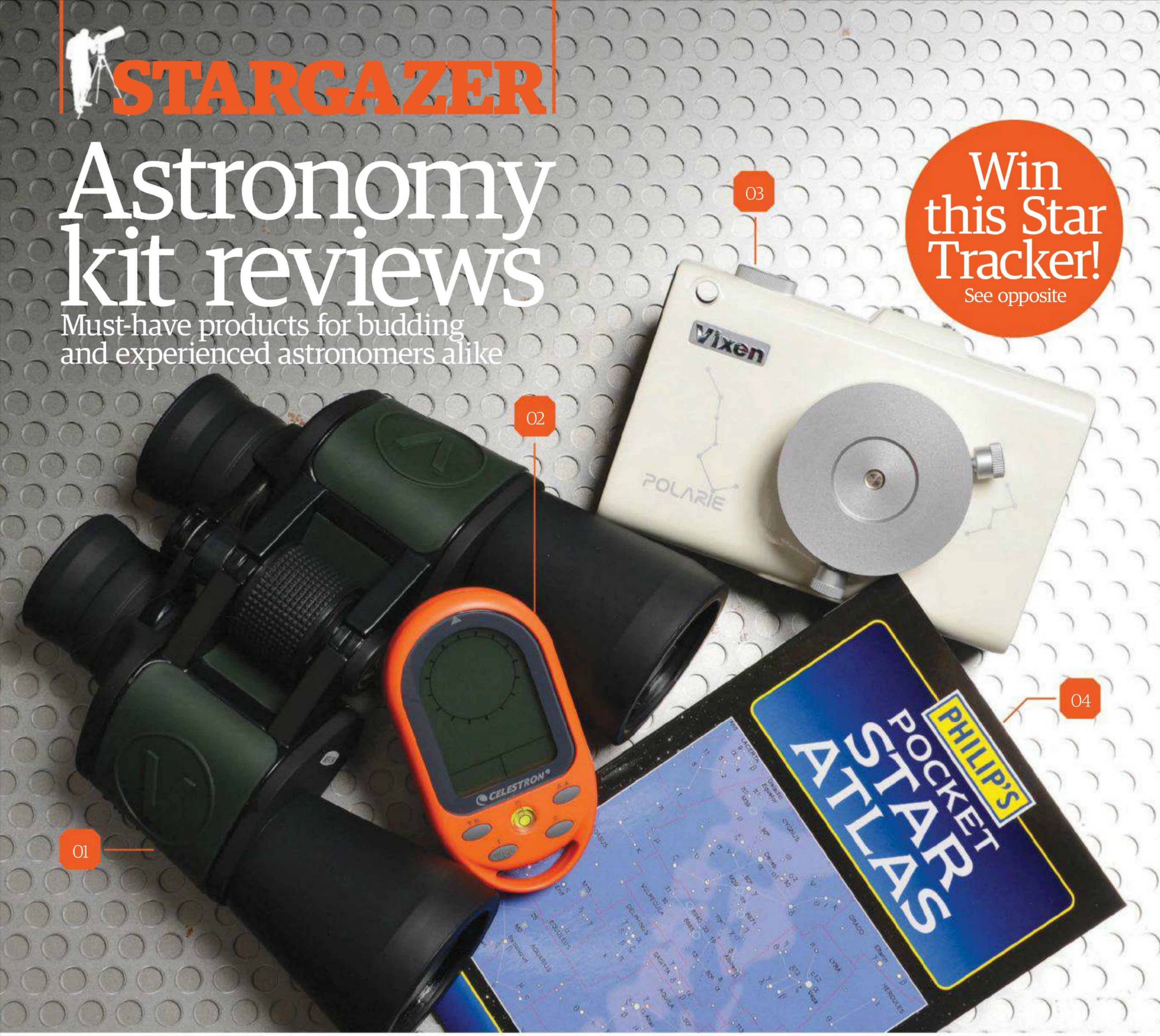
One of this telescope's greatest features is its ability to observe star clusters and nebulas. It does a very good job of seeing deep sky objects, so if you want to explore the universe as a whole and not just the Solar System then you'll love this telescope.

With a reasonable price level and some great optics to match, the Skyhawk 1145P is a great choice for any astronomer. If you're looking for good all-round views of the night sky, including deep sky objects, then you might want to check it out.

> "One of this telescope's greatest features is its ability to observe star clusters and nebulas. It does a very good job of seeing deep sky objects"

Astronomy kit reviews

Must-have products for budding and experienced astronomers alike



1 Binoculars: **Visionary HD 10x50**

Cost: £109.99

From: www.opticalhardware.co.uk

These excellent Visionary binoculars are a joy to use for any astronomer and a great way to get some quick and easy views of the sky at night. Featuring some high-quality optics and fully coated lenses, these 10x50 (magnification of x10, lens size of 50mm) binoculars not only play the part, but also look the part with a neat green and black rubber body for a professional finish. An included carry case and fold-down rubber eye cups provide protection and comfort, making prolonged observations out and about both practical and fun. ●

2 Digital compass: **Celestron TrekGuide**

Cost: £40

From: www.hama.co.uk

Finding your way around the countryside to find that perfect spot for some stargazing can be difficult, and finding your way back can be even more so! The Celestron TrekGuide will keep track of your location, enabling you to find your way there (and back again) with ease. Not only will it track your direction, but it will also measure the altitude, air and sea pressure in the area, and it can forecast the weather so you'll be able to plan ahead to avoid rain etc. A great and lightweight tool that no astronomer should be without. ●

3 Star Tracker: **Vixen Polarie**

Cost: £399

From: www.astronomia.co.uk

This specialist photographic accessory helps you to take incredible photos of the night sky. Using the Polarie you can capture wide-field images of both distant constellations as well as closer celestial phenomena. It gets rid of star trails by following the motion of the stars, and it looks great as well. The Polarie can be set up in a few minutes, even if you're not familiar with the techniques. A great product for amateurs and pros alike, if you're into astrophotography then you will definitely want to pick one up... or try and win one over the page. ●

4 Book: **Philip's Pocket Star Atlas**

Cost: £4.99

From: www.hama.co.uk

If you want a guide to the night sky that you can use anywhere in the world then this is ideal. *Philip's Pocket Star Atlas* contains various maps of the entire night sky, with each map showing the constellations, stars and more. Elsewhere there is also useful astronomical data, including observing tips and scientific information on some celestial bodies, such as illustrations showing the rotation of the Earth around the Sun and which stars can be seen when. This is a useful book for any astronomer and well worth its bargain price of £4.99. ●

Find out more about the Vixen Polarie at **www.vixenpolarie.co.uk**

WIN £650 of astrophotography kit!

Get your hands on these excellent astrophotography accessories in this month's competition

The Vixen Polarie, supplied to us by Astronomia (**www.astronomia.co.uk**), is a brilliant photographic accessory that enables you to take pin-sharp images of stars and entire constellations. It is designed to follow the apparent motion of the stars caused by the Earth's rotation, eliminating star trails.

Using the Polarie with a standard tripod and any digital camera weighing up to two kilograms (4.4 pounds), you can capture fantastic shots of the night sky, image shooting stars or just snap the Milky Way. The Polarie uses very accurate stepping motors and operates on two AA batteries, and it's designed to withstand moisture such as dew, so you'll have no problems using it outdoors.

Also included are a polar scope, quick locator compass and a ball-and-socket panhead, so you'll be fully kitted out to start shooting straight away.

Camera and tripod not included

For your chance to win just answer this simple question:

Q: What does NASA stand for?

A. Not Another Space Agency

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C. Next Amazing Space Adventure

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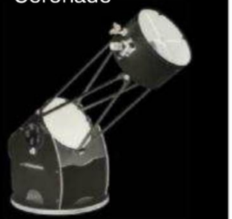

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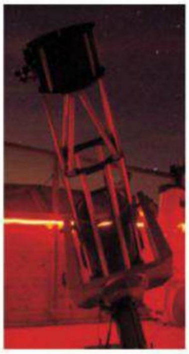

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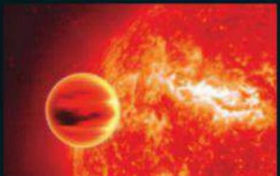

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Hawking took part in a zero-gravity flight in 2007

Stephen Hawking

One of the most lauded astrophysicists of all time whose theories continue to shape our understanding of space

Stephen William Hawking was born in Oxford, England, on 8 January 1942, although he moved to London with his family after WWII. Like many other notable scientists, including Albert Einstein, Hawking did not particularly excel at school and readily admitted that he did little work, often focusing instead on his own projects outside the classroom.

However, this didn't stop him from getting a place at Oxford University to study physics after finding out his preferred option of mathematics was unavailable. He went on to do a PhD in cosmology at Cambridge University and began his pioneering research that has seen him become one of the most respected names in the field.

In his early 20s, Hawking was diagnosed with amyotrophic lateral sclerosis (ALS) and given just months to live. The disease gradually restricted his movement to the point that he can only move his eyes and one cheek today, while a bout of pneumonia in 1985 robbed him of his speech. He now speaks through a voice program controlled by his right cheek, which allows him to piece together sentences, paragraphs and even entire lectures.

Undeterred by his condition, Hawking has led a remarkable career and continues to defy the odds with regards to his life expectancy. After his PhD he worked on a groundbreaking theory with friend and colleague Sir Roger Penrose that concluded the universe was full of tiny black holes immediately after the Big Bang. Later, in 1974, he worked with Israeli theoretical physicist Jacob Bekenstein to show that black holes emit information and material in jets of radiation, referred to today as Bekenstein-Hawking radiation.

Hawking's career is littered with accolades, including a CBE from the Queen of England and the Presidential Medal of Freedom. He was also the Lucasian Professor of Mathematics at Cambridge from 1979-2009, a position once held by Sir Isaac Newton.

He has published many books too, including *A Brief History Of Time*, which shot to the top of the bestsellers' list in 1988 and stayed there for a record-breaking 237 weeks.

Hawking's remarkable mind has seen him become one of the most well-known figures in cosmology, and he continues to conduct research and give lectures. His fascination with the subject extends to space exploration and he wants to visit space himself. After flying on a zero-gravity Boeing 727 in 2007, Hawking is now scheduled to journey into the cosmos aboard Sir Richard Branson's Virgin Galactic when it comes into service. While it might be just a short trip to space aboard Virgin Galactic, his continuing life's work is sure to be remembered long into the future. ●

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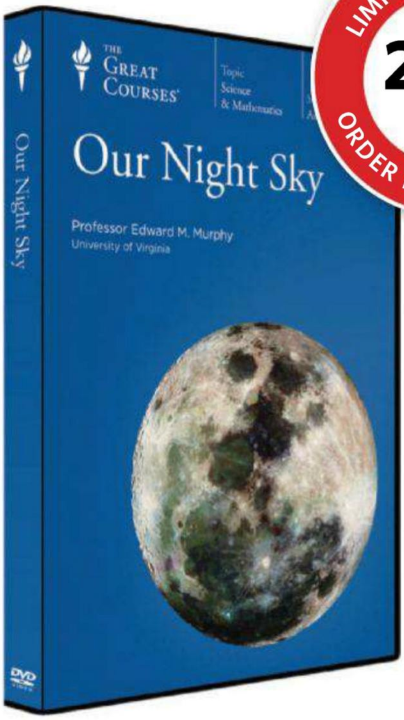

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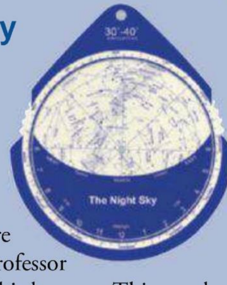

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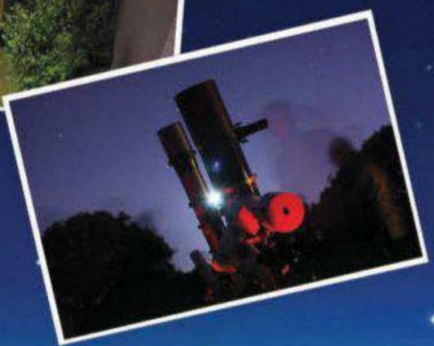

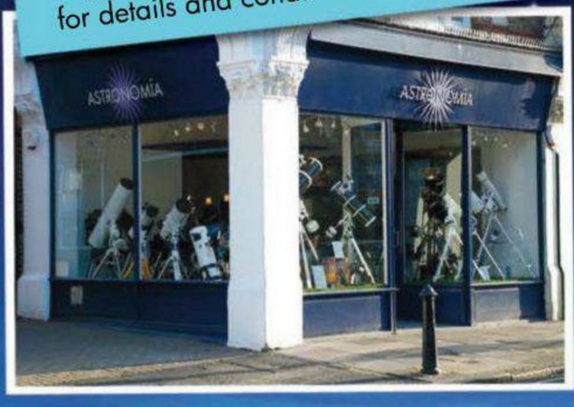

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